PB-244 117

DESIGN, CONSTRUCTION, AND TESTING OF A COMMERCIAL PROTOTYPE DISC DILUTER

W. H. Hedley, et al

Monsanto Research Corporation

Prepared for:

National Environmental Research Center

July 1974

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

233050

NTIS

EPA-650/2-74-055

July 1974

PB244117

Environmental Protection Technology Series

DESIGN, CONSTRUCTION, AND TESTING OF A COMMERCIAL PROTOTYPE DISC DILUTER

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. Department of Commerce
Springfield, VA 22151

Office of Research and Development
U.S. Environmental Protection Agency
Washington, D.C. 20460

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. PB 244 117
EPA-650/2-74-055		

4. TITLE AND SUBTITLE	5. REPORT DATE
Design, Construction, and Testing of a Commercial Prototype Disc Diluter	July 1974
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
W.H. Hedley, H.R. DuFour, W.R. Fairheller, D.L. Harris, T.L. Peltier, and M.D. Schumacher	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Monsanto Research Corporation Dayton Laboratory Dayton, Ohio 45407	1AA010, ROAP No. 26AAP
	11. CONTRACT/GRANT NO.
	68-02-0716
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
U.S. Environmental Protection Agency National Environmental Research Center Chemistry and Physics Laboratory Research Triangle Park, North Carolina 27711	Final
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

EPA is investigating interface systems for stack gas conditioning so that various pollutant gas monitors can be adapted to source monitoring. One of these systems is the disc diluter. The system dilutes high concentration stack gases and conducts them to a point outside the stack where ambient air monitors can be used to measure the concentration.

The objectives of this study were (1) to construct a prototype of an EPA-designed research model, (2) to test the device in a laboratory controlled stack atmosphere, and (3) to field test the device at actual test sites. The prototype disc diluter was constructed and laboratory tested to determine its operating parameters. Following minor modifications, the prototype was field tested at a coal-fired electric generating plant and on a gas-fired steam generator.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

PRICES SUBJECT TO CHANGE

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release Unlimited	UNCLASSIFIED	81
	20. SECURITY CLASS (This page)	22. PRICE
	UNCLASSIFIED	4.75/2.25

EPA Form 2220-1 (9-73)

EPA-650/2-74-055

DESIGN, CONSTRUCTION, AND TESTING OF A COMMERCIAL PROTOTYPE DISC DILUTER

by

W.H. Hedley, H.R. DuFour, W.R. Fairheller,
D.L. Harris, T.L. Peltier, and M.D. Schumacher

Monsanto Research Corporation
Dayton Laboratory
Dayton, Ohio 45407

Contract No. 68-02-0716

ROAP No. 26AAP

Program Element No. 1AA010

EPA Project Officer: James B. Homolya

Chemistry and Physics Laboratory
National Environmental Research Center
Research Triangle Park, North Carolina 27711

Prepared for

OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

July 1974

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

TABLE OF CONTENTS

		Page
I.	INTRODUCTION	1
II.	SUMMARY	3
III.	CONCLUSIONS AND RECOMMENDATIONS	5
IV.	DESIGN, CONSTRUCTION AND OPERATIONAL PRINCIPLES	7
V.	LABORATORY TESTING	15
	Description of Laboratory Apparatus	15
	Simulation Chamber	20
	Disc Wear and Leakage	22
	Warm Up Time for Diluter Head	24
	Disc Hole Flushout	25
	Volumetric Correction Factor	32
	Effects of Particulates	39
VI.	FIELD TESTING	43
	Field Testing at DP&L Coal-Fired Boiler	43
	Field Testing at MRC Gas-Fired Boiler	47
VII.	DISCUSSION OF RESULTS	55
VIII.	APPENDIX A	

LIST OF FIGURES

		Page
1	Flow Schematic of the Disc Diluter System	9
2	Disc Diluter Head Assembly	10
3	Disc Head - Demonstration of Sample Collection	13
4	Disc Diluter Laboratory Testing Design	16
5	Assembled Disc Diluter Head, Extension Tube, and Termination Section	17
6	Termination Section	17
7	Disc Diluter Field Assembly in the Stack Simulation Test Chamber	18
8	Disc Diluter Flow Diagram	19
9	Schematic of Stack Simulation Test Chamber	21
10	Calculation of Theoretical Concentration of Diluted Sample Gas	26
11	Calibration Gas VCP Curve	40
12	Stack Gas VCP Curve	41
13	Disc Diluter Assembly for Field Sampling	42
14	Disc Diluter Field Assembly at DP&L	44
15	EPA Method 6 Sampling Train, Digital Thermometer, and Disc Diluter Field Assembly at DP&L	44
16	Disc Diluter at MRC Boiler Test Stack	49

LIST OF TABLES

		Page
1	Disc Diluter Laboratory Testing Data - Calibration Gas	28
2	Disc Diluter Laboratory Testing Data - Stack Gas	31
3	Disc Diluter Laboratory Testing Data - Stack Gas	33
4	Disc Diluter Laboratory Testing Data - Calibration Gas	38
5	Disc Diluter Field Testing Results at Dayton Power and Light Company	48
6	Disc Diluter Results at Monsanto Research Corp.	52

SECTION I

INTRODUCTION

The Environmental Protection Agency (EPA) has investigated the feasibility of interfacing ambient air monitors to the source of emissions by incorporating a dilution device into a sampling system. Techniques presently in use for source emission measurements generally require some type of particulate removal system and a device to reduce the water vapor to a level that is compatible with currently available continuous monitors.

A research prototype has been developed which dilutes the stack gas sample in-situ by mechanical means, thereby reducing particulate and water vapor concentrations in the gas sampling line to a level at which filters, heat-traced tubing, and/or condensation systems are no longer necessary for continuous instrument operation.

This contract effort is concerned with the development of a commercial prototype disc diluter. The design and construction of the device was based on the principles investigated by the EPA in the research prototype.

The prototype was designed to (1) provide the necessary dilution to be compatible with ambient air sampling devices for SO_2 and NO_x, (2) reduce the particulate and water vapor level to values that will not interfere with the ambient air sampling devices, and (3) be simple to operate and reliable for long-term sampling programs.

The work on this project was done in three phases: Phase I, design, construction, and operation principles; Phase II, laboratory testing; and Phase III, field testing of the apparatus.

The design, construction, and operation principles section of this report contains a detailed description of the disc diluter and its associated equipment. Diagrams and pictures of the various parts that comprise the disc diluter are shown. Variations in design from the original research prototype are given and explained. A detailed description of the operating principles is also given. This includes a flow diagram showing the flow of the various gases involved.

The laboratory testing section of the report is quite detailed. The numerous tests on the disc diluter assembly are described in this section. Diagrams of the testing apparatus and the disc diluter are shown. The problems that arose during the laboratory testing are discussed along with the solutions to the problems which were used. The problems that were encountered in calibration, in choosing the disc material, in finding the correct volume of sample, and in disc hole flushout are all discussed.

The field testing section describes the two field tests which were run using the disc diluter and includes the results of the tests. One test was conducted on a coal-fired boiler at the Dayton Power and Light Company's F. M. Tait Station. The SO_2 concentration of the stack gas was measured. The other test was conducted on a natural gas-fired boiler at Monsanto Research Corporation. The NO_x concentration of the stack gas was measured. Pictures of the testing equipment at the stack locations are included. The problems encountered are discussed along with the results of the tests.

An operations manual for the commercial prototype disc diluter has also been prepared. The manual contains a complete and detailed description for using of the disc diluter and, in addition defines the interfacing of the ambient air monitor to the disc diluter apparatus.

SECTION II

SUMMARY

The purpose of this effort was to develop a commercial prototype disc diluter device based on a research design developed at EPA. The device was to be constructed, tested in the laboratory, and finally demonstrated at actual industrial test sites.

A prototype disc diluter was constructed in the instrument development shop of MRC. Initial laboratory testing of the device indicated that several modifications could be made on the diluter to improve its performance. An airtight housing was also designed and installed on the diluter head to reduce leakage, and the disc material was changed from Teflon to Delrin® for improved wear characteristics. Another small design change was made in the method of diluent gas introduction into the dilution chamber to improve hole flushout.

Continued laboratory testing proved that a correction factor was necessary in the theoretical dilution ratio to determine pollutant concentration because of contraction of the higher temperature stack gases at ambient temperatures. Testing under high particulate concentrations showed no additional problems for the dilution device.

Field testing of the disc diluter at coal-fired and gas-fired power plants illustrated only one further problem. At temperatures above 300°F the Delrin® disc proved insufficient. A disc of Karak was developed and successfully tested at temperatures up to 550°F.

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

The disc diluter has proved to be an effective interface system for conditioning stack gases for analysis in ambient level monitors. Excellent results were obtained under high moisture, particulate, and pollutant concentrations and over a range of temperatures from ambient to 550°F. Comparative testing with EPA Method 6 for SO_2 showed only 4 to 8% deviation between the Method and the disc diluter. NO_x runs with Method 7 gave 15 to 41% deviation between the two methods. However, it is felt that since Method 7 is an instantaneous method, it may not be the correct way to evaluate a continuous monitor. It is suggested that a more exact method be used to validate the diluter's NO_x capabilities.

More long range testing is recommended to illustrate the diluter's use as a continuous source monitor. Improvement in the flow control of the various gases is also recommended for the long range tests by employing a feedback control system. Another recommended improvement is that the volumetric correction factor be automatically applied to the readout or recording device through application of the proper circuitry based on a stack gas temperature monitor's input.

Contingent on these basic improvements and the results of long range tests, it is our belief that the disc diluter has made a substantial contribution to the state of stack gas conditioning concepts and will be a valuable tool in future gas monitoring applications.

Preceding page blank

SECTION IV

DESIGN, CONSTRUCTION AND OPERATIONAL PRINCIPLES

The objective of the design of the disc diluter was to interface ambient air monitors with stack monitoring situations. The problem that occurs in an attempt to monitor stacks with ambient instruments without a sample conditioning system is that such instruments cannot be subjected to the normal in-stack environment. Extremely high particulate levels are often encountered in exhaust gases. Temperature and moisture levels of the exhaust gas may also be too high to be directly fed into air monitors. Since the air monitors are sensitive only to certain gases, contaminate gases must be removed.

Particulate levels are lowered by two mechanisms in the disc diluter. The design of the head permits introduction of the stack gas into the sampling opening perpendicularly to the stack gas flow, thus eliminating some larger particles by their inertia. Concentration levels of smaller particles are reduced by the many-fold dilution of the remaining sampled gas. Dilution with dry clean air also reduces the concentration of the gaseous contaminants and the moisture content to a level compatible with the ambient analyzers. To some extent, temperature reduction is achieved by introduction of the diluent air. However, in-situ dilution causes increases in the temperature of the diluent. The major temperature reduction is achieved by the residence time of the sample in the total system at ambient conditions.

The unit consists of three basic components.

(1) Drive Module - This system incorporates the disc diluter head assembly, extension tubes, and drive mechanism.

Preceding page blank

(2) Control Console - This system incorporates a RPM controller for the drive mechanism, an associated tachometer read-out, and three flowmeters to illustrate the control of vacuum, diluent gas, and calibration gas flows.

(3 Ambient Air Monitoring Device - The choice of units is optional; and Enviromet rics SO_2/NO_x analyzer was used on this program. The operational characteristics of the ambient monitor define many of the system operating parameters.

A flow schematic of the disc diluter system is shown in Figure 1.

A complete set of blueprints showing construction details and dimensions has been included in Appendix A.

The disc diluter head assembly consists of several parts as illustrated by Figure 2. The rotating disc is constructed of a polymeric material, and has a thickness of 0.25 inch and an outside diameter of 2.5 inches. Teflon, Delrin®, and Karak discs were used in the various phases of the testing program. The disc has eight holes of known volume which collect stack gases and carry the samples to the dilution chamber in the head. The disc is located between two stationary plates, the gas sampling plate, and the disc head body. The disc head body is attached to the probe extension housing and allows four lines to enter the head, one each for calibration gas, vacuum, inert gas inlet, and diluted gas outlet. The gas sampling plate contains sample inlet ports which allow the transfer of stack gas to the disc holes. The matching surfaces of the sampling plate, disc, and body are machined flat to assure an airtight seal and to eliminate the build-up of particulates. The plates are held together by an outer housing which attaches to the body section of the head. A locating pin in this housing assures the proper alignment of

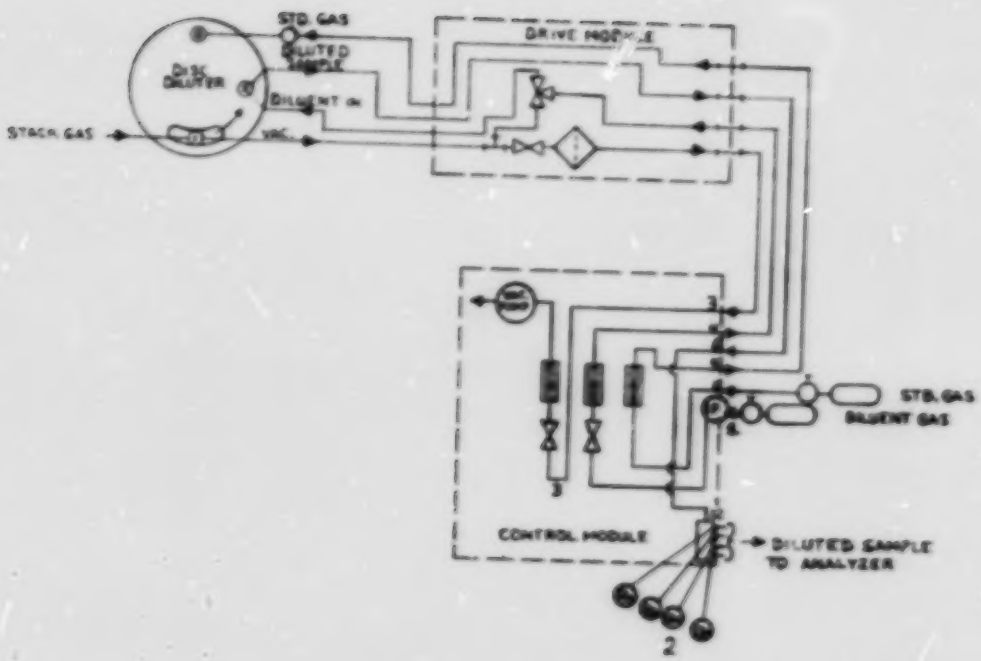


Figure 1. Flow Schematic of the Disc Diluter System

Figure 2. Disc Diluter Head Assembly

all sampling ports and lines. A spring washer and a closure ring maintain tension on the rotary disc. The disc is rotated by a drive shaft connected to a variable-speed, reversible motor located in the drive module.

The extension tube consists of an outer tube housing containing the four gas transporting lines and the drive shaft for rotating the disc. These are four extension assemblies of various lengths to allow for placement of the diluter head at the desired location in stacks of different diameters.
The ends of the extension assemblies have matching flanges that allow transmission of the drive shaft power as well as O-ring-sealed gas connections for the four gas tubes. The extensions can be used alone or in tandem for various lengths.

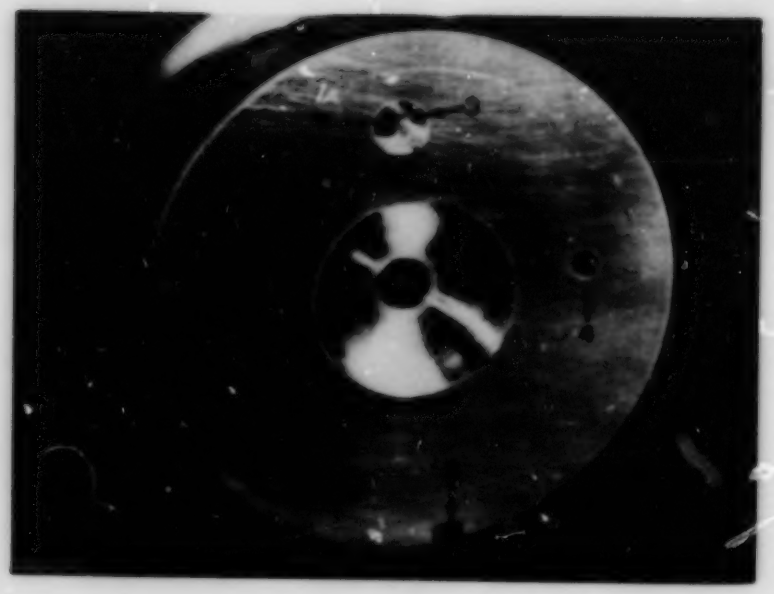
The extension assembly is bolted to the drive module where the drive power motor is located. This module serves to distribute the plumbing and electrical lines to the umbilical line. It also holds the vacuum source filter and drier. The purpose of the filter is to clean and dry the stack gases that are drawn into the vacuum system before reaching the umbilical line or vacuum pump.

Gases are transported between the drive module and the control module through a ten foot umbilical line. The lines are equipped with quick-connect couplings for easy separation of the drive and control modules when not in use. All lines that carry pollutant-bearing gases are made of Teflon or stainless steel to eliminate absorption of the pollutant onto the walls of gas line surfaces.

Speed of rotation of the disc is determined at the control module. It becomes necessary to rotate the disc at various speeds under different conditions and these speeds are set by the RPM controller and read on the associated tachometer. Float type

flowmeters, which are located in the control module, are used to measure the flow rate of the exhaust gas being sampled. Three similar flowmeters are used to determine the amount of gases sampled. The flows that are measured include the vacuum flow, the dilute gas flow, and the standard gas flow. The module also contains the vacuum source pump and has connections for introduction of calibration gas and diluent gas, and multiple connections for distribution of diluted sample gas to the analyzers.

Figure 3 illustrates the disc head and is used to demonstrate how the samples are collected. The unit can sample either stack gas or calibration gas depending upon the direction of rotation of the disc head. As the disc rotates counterclockwise, the holes in the disc line up with the port in the gas sampling plate and the vacuum port in the body. Stack gas is drawn through the hole and captured. Continued rotation causes the disc holes to coincide with the dilution chamber in the body of the head. Here the stack gas sample is flushed out by a measured flow of diluent gas (air). The diluent gas is introduced into the chamber through an injection nozzle that causes increased gas exchange in the sample hole of the disc and leaves the chamber through an exit hole. If the disc is rotating clockwise, the hole in the disc passes the calibration gas supply port and is filled with gas. As the disc continues to rotate, the holes with their charge of calibration gas are transported to the dilution chamber where they are flushed with diluent air. The diluted calibration gas is transported through the system the same as stack gas and is analyzed with an ambient air monitor. A check valve inside the head prevents the back flow of stack gases into the calibration gas line from outside the diluter head.



1. Dilution chamber
2. Diluted sample gas outlet
3. Diluent air inlet
4. Vacuum inlet
5. Gas sampling plate holder locating slot
6. Calibration gas outlet

Figure 3. Disc Head-Demonstration of Sample Collection

The diluted gas sample or calibration gas is transported from the head assembly through the sample outlet tube in the extension tube assembly to the drive module. The sample gas continues through the umbilical tube to the control module. In the control module the sample gas flow is sent to the ambient air monitor for analysis. The contaminants in the stack are determined by measuring the clean, dry, diluted sample with the ambient air monitor and by calculation converting this measurement to the actual stack concentration.

SECTION V

LABORATORY TESTING

The laboratory testing phase was an extensive investigation into the operating parameters of the disc diluter. Several necessary modifications to the unit were implemented to allow reliable and accurate calibration and measurements of stack gases. This program successfully eliminated the need to make major changes during the field sampling phase of the program.

DESCRIPTION OF LABORATORY APPARATUS

Initial laboratory testing was performed with the disc diluter head assembly and extension tube attached to a termination section. The testing facility flow diagram is shown in Figure 4. The termination section provided a connection for the four gas lines used and is shown in Figure 6. The initial assembly is shown in Figure 5. The disc was turned by a variable speed motor attached to the drive shaft of the termination section and the gas lines were attached to the tubes. The construction of this facility allowed laboratory testing to be started while the drive and control modules were being completed. The operating principles were basically the same as with the complete disc diluter field assembly.

All laboratory testing was done with SO_2 gases. Figure 7 shows the Envirometrics Inc. SO_2 analyzer and control module that was used in this and all subsequent laboratory testing for measuring the diluted sample gas produced by the disc diluter. A flow diagram of the disc diluter and SO_2 analyzer is shown in Figure 8. The entire initial testing facility was mounted on a moveable rack to allow ease of placement of the disc diluter in the stack simulation chamber discussed later. All lines that carried SO_2-bearing gases were either stainless steel or Teflon to minimize SO_2 reactions with system components.

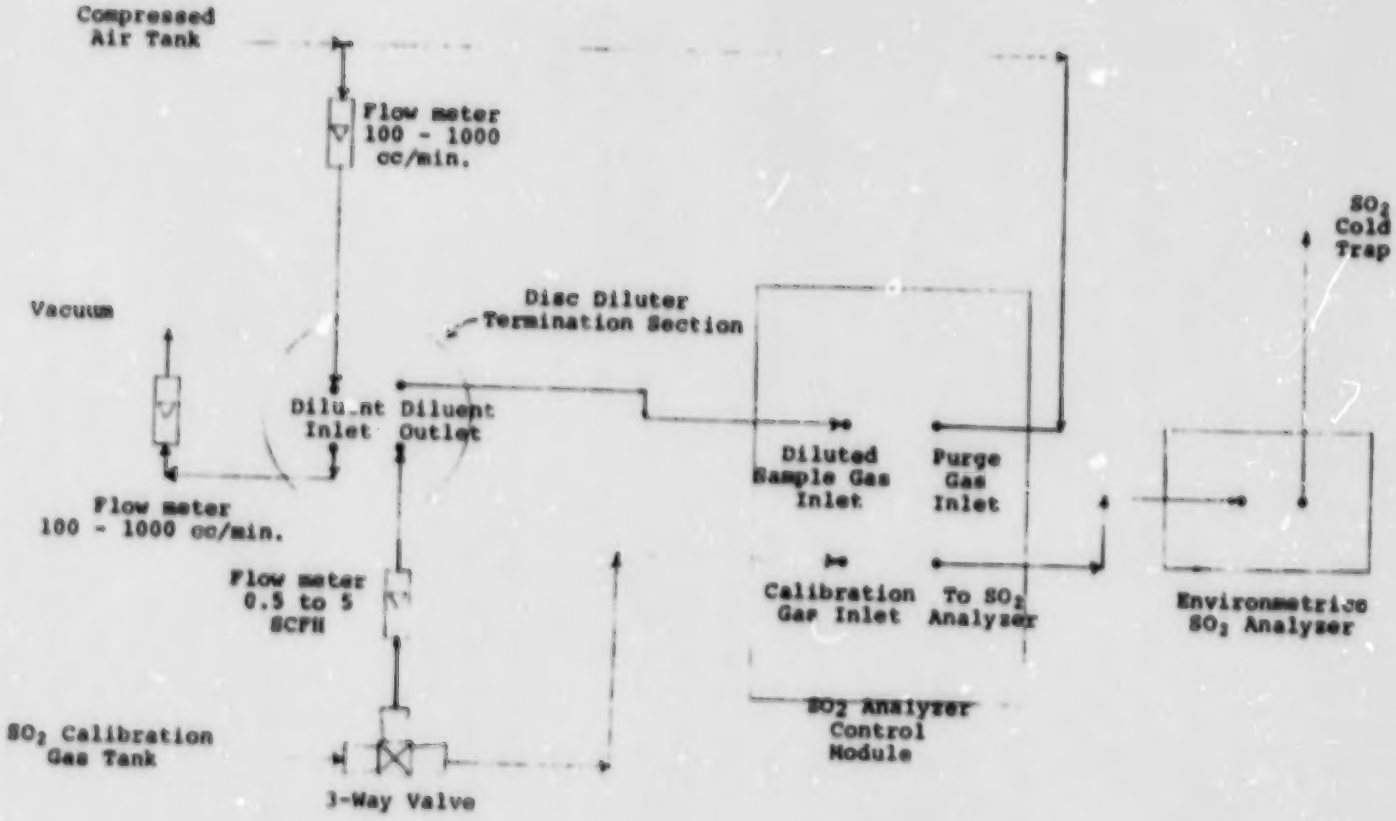


Figure 4. Disc Diluter Laboratory Testing Design

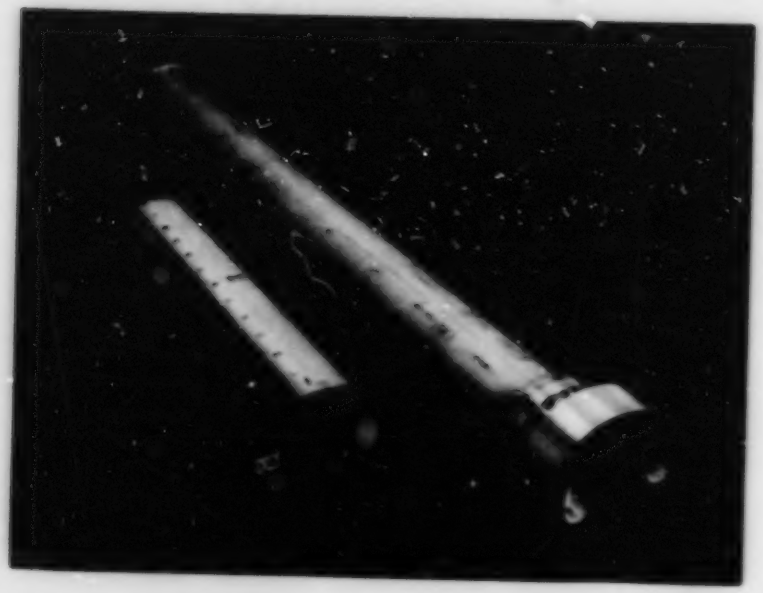


Figure 5. Assembled Disc Diluter Head, Extension Tube, and Termination Section

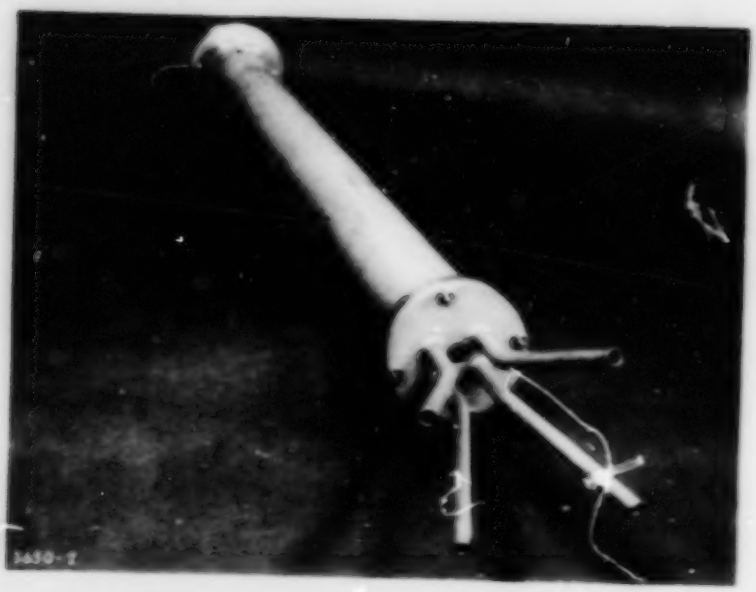


Figure 6. Termination Section

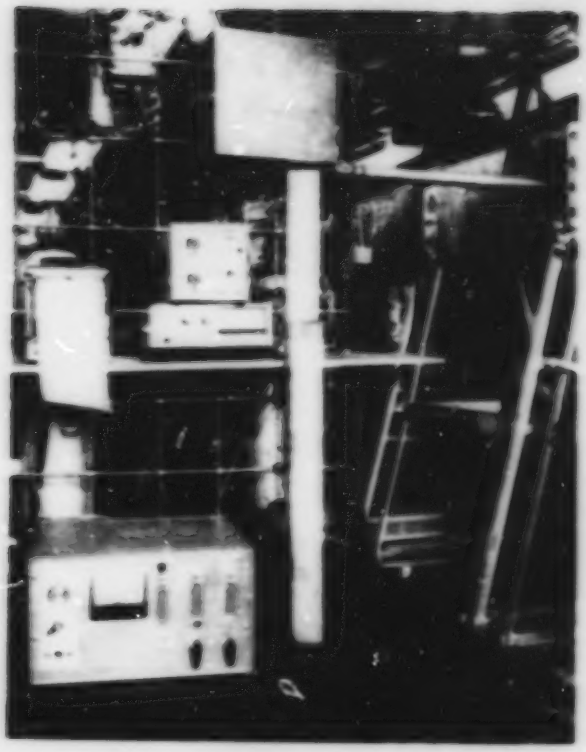


Figure 7. Disc Diluter Field Assembly in the Stack Simulation Test Chamber

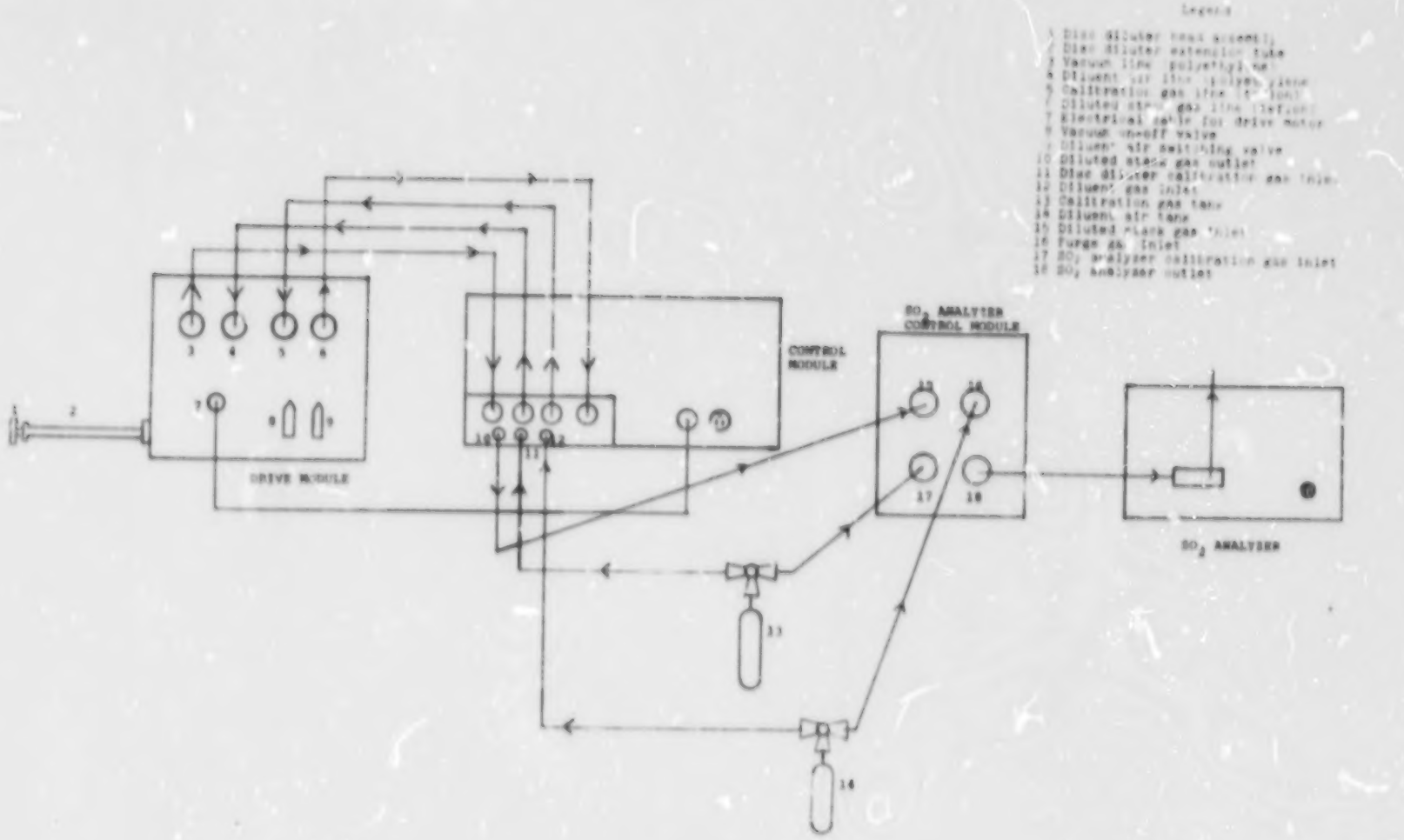


Figure 8. Disc Diluter Flow Diagram

The diluent air was supplied from a compressed breathing air tank to the inlet of the disc diluter termination section and then to the dilution chamber in the disc diluter head. The vacuum line drew in the sample gas and the disc transported the sample gas to the dilution chamber where the diluent gas flushed out the hole in the disc. The diluted sample gas then transported from the diluter head to the outlet on the termination section. The diluted sample gas first went to the SO_2 analyzer control module and then to the Envirometrics Inc. SO_2 analyzer. The purpose of the control module was to send either SO_2 calibration gas directly to the analyzer for calibration or diluted sample gas to the analyzer for measurement of SO_2 concentration. The purge gas was compressed air used to purge out residual SO_2 from the analyzer. The calibration of both the disc diluter and the SO_2 analyzer could be accomplished by feeding a SO_2 calibration gas with a three-way valve into either the disc diluter or the SO_2 analyzer.

SIMULATION CHAMBER

Most of the laboratory testing was performed in a stack simulation chamber. This chamber is illustrated in Figure 9. Room air was drawn in and heated to give a desired stack temperature of up to 300°F. SO_2 gas was fed into the entrance orifice and mixed with heated room air by the diffuser plate to give a homogeneous SO_2-air mixture. Particulate fly ash can be fed into the chamber from the dust feeder to simulate stack particulate flow. The large scale turbulence (produced by the baffle plate) is broken up by the perforated diffuser plate, resulting in a uniform dust distribution and a flat velocity profile at the upstream sampler position where the disc diluter was tested. The velocity could be varied by means of a diaphragm on the exhaust blower.

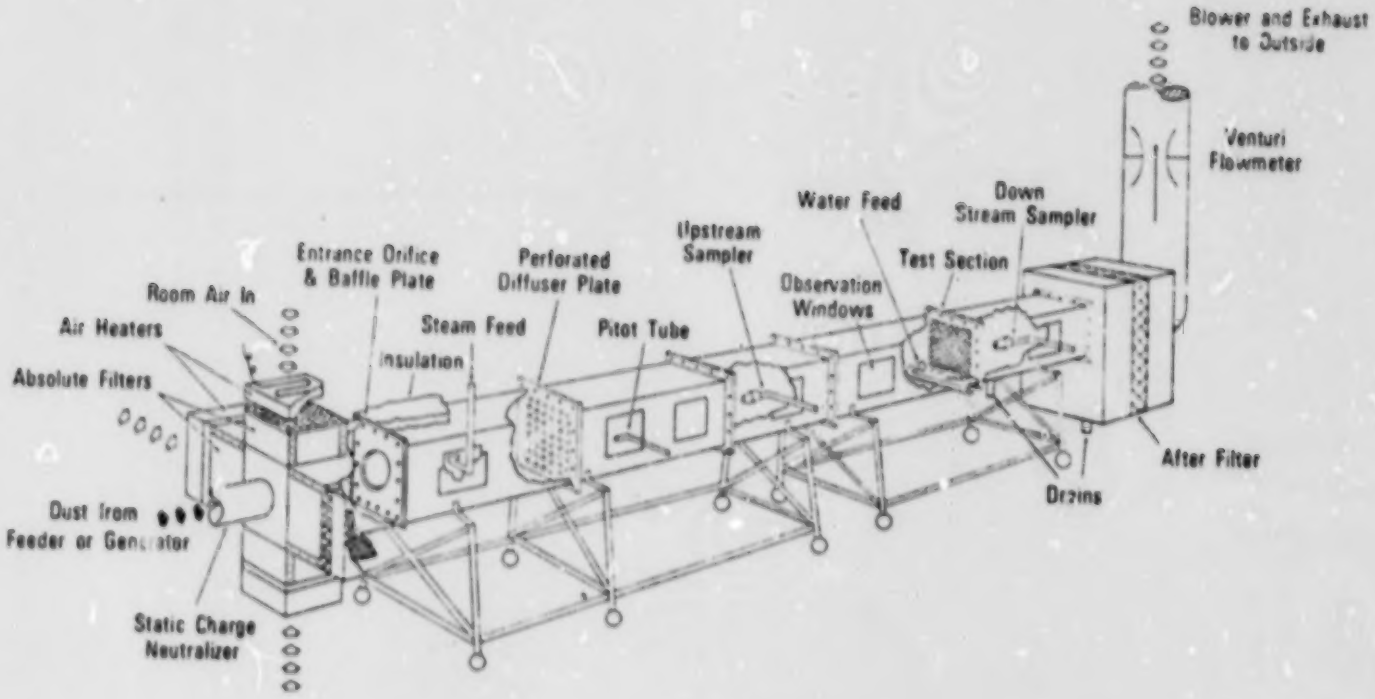


Figure 9. Schematic of Stack Simulation Test Chamber

DISC WEAR AND LEAKAGE

Initial laboratory tests were conducted to determine the disc wear and air leakage in the disc diluter head during operation. The first disc tested was a four-hole Teflon disc with a thickness of 0.260 inch. This disc wore excessively, which resulted in leakage of diluent air from the head. The leakage was due to the shaving of Teflon particles from the Teflon disc by the sharp edges of the sample and calibration gas inlet ports on the diluter head sampling plate. After approximately 1200 revolutions of the disc, sufficient Teflon particles had built up between the Teflon disc and the stainless steel face to cause the leak.

Another disc of a different type of Teflon was fabricated and tested with the same results. In an attempt to combat the problem, the Teflon disc and steel rubbing surfaces were refinished to a high polish, and the spring tension on the Teflon disc was reduced to decrease the wear. Finally, the disc head was grounded to allow static charges to be dissipated. None of these efforts proved to be a successful solution to the excessive wear problem.

The next step was the selection of a different disc material. DuPont's Delrin® was selected as a good replacement for Teflon. Delrin® is a polyformaldehyde thermoplastic which has chain terminations to prevent polymer unzipping. This material is crystalline, tough, opaque, and has a relatively low coefficient of friction. It does not react with SO_2, nitrogen oxides, or air at ambient or elevated temperatures. Its melting point is above 200°C (392°F), but is becomes rubbery and cannot be used near the melting point.

DuPont Delrin® was extensively investigated as a disc material and was found suitable for use in the disc diluter. A principal problem in substituting Delrin® for Teflon was the much higher rotational friction. This problem was overcome by reducing the spring tension on the Delrin® disc to allow it to operate more freely. At the same time the diluent air tank pressure was reduced to minimize the leak rate at the lower spring tensions. Additionally, an eight-hole disc configuration was used with the Delrin® disc to allow the disc to give useful dilution ratios at lower RPM's, resulting in less wear.

At the lower spring tension and diluent air pressure the pressure differential from atmospheric for the flowing diluent stream was 5 cm Hg maximum. The average leak rate at this pressure was less than 1 cc/minute even after over 4000 revolutions at ambient temperatures. At 280°F after 3200 revolutions (about 160 minutes of operation at 20 RPM) the leakage rate remained at less than 1 cc/minute. This leakage rate will have an insignificant effect on the results because it is substantially less than the diluent flow of 200-800 cc/minute.

The eight-hole Delrin® disc gave excellent wear characteristics at both high and low temperatures. The wear at ambient temperatures and 280°F is not noticeably different after over 3200 total revolutions. Delrin® does not flake as Teflon does and the particles produced by wear do not significantly build up on either the disc or steel face surfaces.

The wide spread use of Teflon in air monitoring systems is a result of its inert characteristics; however the characteristics of Delrin® are not as well established. The fact that the Delrin® disc gave identical results as the Teflon disc under the same operating conditions would indicate that Delrin® does not show any sorption characteristics and is at least as inert as Teflon for the disc diluter application.

WARM UP TIME FOR DILUTER HEAD

The temperature rise times of the disc diluter head were determined. A thermocouple was threaded through the termination section and extension tube and into the rear of the disc diluter head close to its center of mass. The disc diluter was placed in a temperature controlled oven and the diluter head temperature rise times measured on a digital thermometer. As would be expected, the temperatures of the diluter head asymptotically approached the oven temperature. Times for the head to reach 95% of the oven temperature are given below.

DILUTER HEAD TEMPERATURE RISE TIMES

Average Oven Temperature (°F)	Oven Temperature Fluctuation (%)	Time Needed to Reach 95% of Oven Temperature (Min.)
259	4	56
295	4	47
300	7	48
349	3	53

The apparent randomness in these times is ascribed to the random temperature fluctuations of the oven which gave rise to irregular temperature driving forces for heat transfer.

It is apparent that the disc diluter head should be placed in a 250-350°F stack at least one hour prior to sampling to allow the head to reach at least 95% of stack temperature. At lower stack temperatures a lesser amount of time would be necessary because of a lower temperature differential. At 95% of stack temperature no condensation of SO_2, NO_x, or water would be expected in 250-350°F stacks because these components boil at lower temperatures. At the 95% level the condensation of high boiling stack gas components which might interfere with diluter head operation would not be expected except at saturation levels.

Therefore the general provision of placing the disc diluter head into the stack one hour before sampling would seem to allow the head to equilibrate sufficiently for SO_2 and NO_x analysis.

DISC HOLE FLUSHOUT

Laboratory tests were performed to determine the extent of the disc hole flushout by the stream of diluent air. Various concentrations of SO_2 in stack gases and SO_2 calibration gas were measured with the disc diluter to determine the extent of disc hole flushout of the eight-hole Delrin® disc. The theoretical concentration of diluted sample SO_2 gases can be calculated from the equation in Figure 10. This is the theoretical concentration of a diluted stack or pollutant calibration gas if the disc hole is completely flushed out. A sample calculation is also shown in the figure. In actual experiments, the diluted sample gas was measured by the Envirometrics SO_2 analyzer, and this measured SO_2 value was divided by the theoretical SO_2 value to give the measured versus theoretical SO_2 ratio. This ratio was indicative of the degree of disc hole flushout obtained, with unity representing complete disc hole flushout.

In initial determinations of disc hole flushout with the eight-hole Delrin® disc nearly complete flushout was obtained with SO_2 calibration gases but only 70-90% flushout was obtained with SO_2 stack gases in the stack simulation test chamber. As expected, diluent flow rates of 200 cc/minute gave lower flushout rates than did 400, 600, and 800 cc/minute with either SO_2 calibration or SO_2 stack gases.

It was decided that the probable reason for this difference in disc flushout was due to an orientation phenomenon between disc holes and the jet of diluent air coming into the dilution chamber.

GENERAL EQUATION FOR THE CALCULATION OF THEORETICAL CONCENTRATION OF DILUTED SAMPLE GAS (POLLUTANT CALIBRATION GAS OR STACK GAS)

$$\text{THEORETICAL CONCENTRATION OF DILUTED SAMPLE GAS (ASSUMING COMPLETE FLUSH-OUT OF DISC HOLE)} = \text{VOLUME OF DISC HOLE} \times \frac{\text{NO. OF HOLES}}{\text{REVOLUTION}} \times \frac{\text{REVOLUTIONS}}{\text{MINUTE}} \times \frac{1}{\text{DILUENT FLOW}} \times \text{CONC. OF SAMPLE GAS (PPM)}$$

Sample Calculation with 0.140" diameter x 0.260" disc holes
8-hole disc
12 RPM
200 cc/minute diluent flow
3502 ppm SO_2 sample gas

$$\text{THEORETICAL } SO_2 \text{ CONCENTRATION OF DILUTED SAMPLE GAS (ASSUMING COMPLETE FLUSH-OUT OF DISC HOLE)} = 6.56 \times 10^{-2} \frac{cm^3}{\text{hole}} \times \frac{8 \text{ holes}}{\text{revolution}} \times \frac{12 \text{ revolutions}}{\text{minute}} \times \frac{1}{200 \frac{cm^3}{\text{minute}}} \times 3502 \text{ ppm } SO_2$$

$$= 108 \text{ ppm}$$

Figure 10. Calculation of Theoretical Concentration of Diluted Sample Gas

As the disc holes rotate clockwise past the dilution chamber for SO_2 calibration gas dilution, the jet of diluent air strikes the disc hole immediately as it reaches the dilution chamber. This gives 100% flushout of the hole for all but 200 cc/minute diluent flows. For stack gas dilutions the disc rotates counterclockwise and the disc holes approach the dilution chamber from the opposite direction. The jet of diluent air does not hit the hole immediately as the hole reaches the dilution chamber, resulting in incomplete flushout.

The dilution chamber was modified by inserting a stainless steel tube into the diluent air inlet at the back of the dilution chamber. The jet of diluent air now hits the disc holes more directly and hits with less diffusion of the diluent air stream. At this point the disc diluter head and extension tube were removed from the laboratory testing facility and attached to the drive module for laboratory testing of the complete disc diluter assembly. Several modifications had to be made in the disc drive train from the drive module motor to insure reliable operation at the relatively high torque needed to drive the Delrin® disc. Also, a misalignment in the drive train was found to cause a leak at the disc diluter head. Several changes were made in the alignment to prevent the disc from being forced away from its steel sealing surface, resulting in a leak of diluent air.

Calibration SO_2 gases were fed into the control module and transferred via Teflon tubing to the calibration gas outlet on the disc diluter head. The results are shown in Table 1. The measured versus theoretical SO_2 gases using the dilution chamber modification discussed previously. This modification apparently provides sufficient turbulence in the dilution chamber to allow complete flushout even at 200 cc/minute. The use of these flow rates would extend the ability of the disc diluter to measure low stack SO_2 concentrations becuase of the lower dilution ratio.

Table 1. Disc Diluter Laboratory Testing Data - Calibration Gas

SO_2 Analyzer & Disc Diluter SO_2 Calibration Gas Conc (ppm SO_2)	Diluent Flow (cc/min)	RPM (±5)	SO_2 Concentration Measured of Diluted Calibration Outlet Gas (ppm)	Theoretical SO_2 Conc Assuming Complete Hole Flushout (ppm)	Measured vs. Theoretical SO_2 Ratio
4055	200	12	42	43	.97
	200	16	41	44	.93
	200	20	55	55	1.0
	200	24	62	66	.94
	400	12	17	17	1.0
	400	16	21	22	.95
	400	20	27	28	.96
	400	24	33	33	1.0
	600	12	12	11	1.1
	600	16	18	19	.93
	600	20	17	18	.94
	600	24	20	22	.91
	800	12	8.4	8.3	1.0
	800	16	11	11	1.0
	800	20	14	14	1.0
	800	24	15	17	.88
212	200	12	6.7	6.7	1.0
	200	16	8.3	8.9	.93
	200	20	11	11	1.0
	200	24	13	13	1.0
	400	12	3.4	3.3	1.0
	400	16	4.5	4.5	1.0
	400	20	5.7	5.6	1.0
	400	24	6.7	6.7	1.0
	600	12	2.3	2.2	1.0
	600	16	3.0	3.0	1.0
	600	20	3.7	3.7	1.0
	600	24	4.2	4.5	.93
	800	12	1.7	1.7	1.0
	800	16	2.1	2.2	.95
	800	20	2.6	2.8	1.0
	800	24	3.1	3.3	.94

However a 200 cc/minute constant flow rate is more difficult to maintain than the others and would be desirable to use only where very low stack SO_2 measurements are being made.

With the Envirometrics SO_2 analyzer at 400 cc/minute diluent flow and 24 RPM, to give a theoretical dilution ratio of 32, it should be possible to obtain accurate measurements of stack concentrations as low as 30 ppm SO_2. With higher RPM's it should be possible to extend the lower limit of stack SO_2 concentrations that can be measured. In the higher concentration there is no problem. At 200 ppm calibration and a theoretical dilution ratio of 127 it should be possible to measure stack SO_2 concentrations in excess of 25,000 ppm SO_2. Use of a high concentration of SO_2 in the calibration gas or using a lower speed of rotation could further increase the concentrations of SO_2 which could be determined in stack gases.

The effective transfer of SO_2 calibration gas to and from the disc diluter head was determined to see if sorption-desorption phenomena were occurring anywhere in the system. A calibration gas mixture of 372 ppm SO_2 by volume in nitrogen was used to calibrate the SO_2 analyzer. This gas was then fed directly into the dilution chamber and the concentration reaching the SO_2 analyzer measured. Also, the 372 ppm SO_2 gas was allowed to flow out the calibration gas outlet on the disc diluter head and directly transported via Teflon tubing to the SO_2 analyzer. In both cases the SO_2 analyzer gave 100% readings which correspond to 372 ppm. Thus, there was a 100% effective transfer of SO_2 calibration gas from the dilution chamber and to the calibration gas outlet on the disc diluter head. No wall or component interactions with the SO_2 calibration gas are apparent that would affect results.

The necessity of having a mixing chamber was determined during the tests concerning flushout. At low RPM's the pulsations at the SO_2 analyzer increased slightly. This would be expected since diluent gas flows constantly while disc holes are flushed out intermittently, resulting in a non-homogeneous diluent stream. However, it was found at the proposed working range of 12-24 RPM that any pulsations due to this phenomenon was not noticeable over normal electrical noise in the Envirometrics SO_2 analyzer. Evidently at these RPM's there is sufficient turbulent mixing in the transfer lines to deliver a homogeneous SO_2 gas stream to the analyzer and thus, a mixing chamber is not necessary.

Stack SO_2 dilutions were performed with the dilution chamber modification in the complete field assembly. These results are shown on Table 2 for ambient and high temperature stack gas. As with the SO_2 calibration gas the measured versus theoretical SO_2 ratios are all close to one for ambient temperatures, indicating complete disc hole flushout. Without the dilution chamber modification the flushout was only 70-90%. The actual stack SO_2 concentration can be found from the following formula:

$$\text{Stack } SO_2 \text{ conc(ppm)} = \text{Measured } SO_2 \times \frac{\text{Theoretical Dilution Ratio}}{\text{conc(ppm)}}$$

At elevated temperatures the dilution chamber modification has caused higher measured versus theoretical SO_2 ratios than had been obtained before. The present measured versus theoretical SO_2 ratios are as a whole higher than those previously found which ranged from 0.74-0.88 in the present configuration. This would indicate that more complete disc hole flushout has been attained.

Table [illegible] - Gas Diluter Laboratory Testing Data - Stack Gas

	Stack Simulation Chamber SO_2 Conc., Temp., velocity	Effluent Flow (cc/min)	NIM (±2%)	SO_2 Concentration Measured of Diluted Sample Inlet Gas(ppm)	Theoretical SO_2 Conc. Assuming Complete Dilution Hole Flushout(ppm)	Measured vs. Theoretical SO_2 Ratio	Theoretical Dilution Ratio
Ambient Temp.	182±4# 73° F. 7.2 ft/sec	200	12	5.2	6.0	.88	[illegible]
		200	16	7.6	8.1	.94	[illegible]
		200	20	10	10	1.0	[illegible]
		200	24	13	12	1.1	[illegible]
		400	12	3.3	3.0	1.1	[illegible]
		400	16	4.0	4.0	1.0	[illegible]
		400	20	5.3	5.0	1.1	[illegible]
		400	24	6.8	6.0	1.1	[illegible]
		600	12	2.2	2.0	1.1	[illegible]
		600	16	2.7	2.7	1.0	[illegible]
		600	20	3.3	3.4	.97	[illegible]
		600	24	4.5	4.0	1.1	[illegible]
		800	12	1.7	1.5	1.1	[illegible]
		800	16	1.9	2.0	.95	[illegible]
		800	20	2.4	2.5	.96	[illegible]
		800	24	3.3	3.0	1.1	[illegible]
Elevated Temp.	110°±2# 285-295° F. 7.5 f'/sec	200	12	28	35	.80	[illegible]
		200	16	35	46	.76	[illegible]
		200	20	43	58	.74	[illegible]
		200	24	52	69	.75	[illegible]
		400	12	15	17	.88	[illegible]
		400	16	19	23	.83	[illegible]
		400	20	23	29	.79	[illegible]
		400	24	26	35	.74	[illegible]
		600	12	9.9	12	.83	[illegible]
		600	16	13	15	.87	[illegible]
		600	20	14	19	.74	[illegible]
		600	24	17	23	.74	[illegible]
		800	12	7.7	8.7	.88	[illegible]
		800	16	9.4	12	.78	[illegible]
		800	20	12	14	.84	[illegible]
		800	24	14	17	.76	[illegible]

VOLUMETRIC CORRECTION FACTOR

The reason that the SO_2 ratio is less than one in the previous section is due to a volumetric change in the diluent gas at the elevated temperature. A volumetric correction had to be made in the EPA prototype and one will be needed also in the MRC disc diluter. The stack SO_2 concentration can be found by applying a volumetric correction factor for the temperature being measured. Intermediate temperatures between ambient and 290°F were investigated to determine what volumetric correction factor is needed at each temperature. Volumetric correction factors for temperatures between 70-300°F were determined for the disc diluter in the laboratory testing facility. Measured versus theoretical SO_2 ratios for stack gas at elevated temperatures turned out to be less than unity, indicated the need for a volumetric correction similar to the one needed with the EPA prototype. Volumetric correction factors were determined both for SO_2 calibration gas and stack gas at various temperatures between ambient and 300°F. The results are shown in Table 3 for stack gas dilutions at 70, 155, 225, and 300°F. The determinations were made as discussed previously in the MRC stack simulation test chamber.

The average measured versus theoretical ratio (AMVTR) has been determined by averaging the individual measured versus theoretical SO_2 ratios for each diluent flow and RPM at a certain temperature. As seen in the testing data the AMVTR goes down with increasing temperature. The AMVTR is unity at ambient temperatures indicating complete disc hole flushout. The reduction in AMVTR with increasing temperature is due then to the reduction in volume of the disc hole gas as it cools to ambient temperature where the SO_2 concentration is measured. The AMVTR results are summarized as follows.

Table 3. Disc Diluter Laboratory Testing Data - Stack Gas

Stack Chamber Temp. (°F)	Stack Chamber SO_2 Conc. (ppm)	Diluent Flow (cc/min)	RPM (A/S)	SO_2 Conc. Measured of Diluted Stack Gas (ppm)	Theoretical SO_2 Conc. Assuming Complete Disc Mole Flushout (ppm)	Measured vs. Theoretical SO_2 Ratio	Avg. Measured vs. Theoretical SO_2 Ratio	Theoretical Dilution Ratio
73	182	200	12	5.9	6.0	.98	1.0	30
		200	16	7.6	8.1	.94		22
		200	20	10	10	1.0		18
		200	24	13	12	1.1		15
		400	12	3.3	3.0	1.1		61
		400	16	4.0	4.0	1.0		46
		400	20	5.1	5.0	1.1		35
		400	24	6.8	6.0	1.1		30
		600	12	2.2	2.0	1.1		91
		600	16	2.7	2.7	1.0		67
		600	20	3.3	3.4	.97		56
		600	24	4.5	4.0	1.1		46
		800	12	1.7	1.5	1.1		121
		800	16	1.9	2.0	.95		91
		800	20	2.4	2.5	.96		73
		800	24	3.3	3.0	1.1		61
150-159 (155)	195	200	12	7.6	7.6	1.0	.99	25
		200	16	9.8	10	.98		19
		200	20	12	13	.92		15
		200	24	14	15	.93		13
		400	12	4.0	3.8	1.1		51
		400	16	5.2	5.1	1.0		38
		400	20	6.5	6.4	1.0		31
		400	24	7.5	7.6	.99		25
		600	12	2.7	2.5	1.1		76
		600	16	3.5	3.4	1.0		57
		600	20	4.0	4.2	.95		46
		600	24	5.0	5.1	.98		38
		800	12	1.9	1.9	1.0		107
		800	16	2.4	2.5	.96		76
		800	20	3.1	3.2	.97		61
		800	24	3.8	3.8	.99		51

Table 3. Glass Diluter Laboratory Testing Data - Stack Gas (cont.)

Stack Chamber Temp. (°F)	Stack Chamber SO_2 Conc. (ppm)	Diluent Flow (cc/min)	RPM (±2%)	SO_2 Conc. Measured of Diluted Stack Gas (ppm)	Theoretical SO_2 Conc. Assuming Complete Disc Hole Flowout (ppm)	Measured vs. Theoretical SO_2 Ratio	Avg. Measured vs. Theoretical SO_2 Ratio	Theoretical Dilution Ratio
220-237 (225)	188 ±2%	200	12	6.0	7.6	.81	.88	25
		200	16	8.9	9.9	.93		19
		200	20	11	12	.92		15
		200	24	13	15	.87		13
		400	12	3.2	3.7	.86		51
		400	16	4.5	4.9	.92		38
		400	20	5.7	6.2	.92		31
		400	24	7.0	7.4	.95		26
		600	12	2.2	2.5	.88		76
		600	16	2.9	3.3	.88		57
		600	20	3.5	4.1	.85		46
		600	24	4.5	4.9	.92		38
		800	12	1.5	1.8	.79		102
		800	16	2.2	2.5	.88		76
		800	20	2.7	3.1	.87		62
		800	24	3.3	3.7	.89		51
300-305 (300)	205 ±2%	200	12	6.7	8.1	.83	.83	25
		200	16	8.8	11	.80		19
		200	20	10	13	.77		15
		200	24	13	16	.81		13
		400	12	3.6	4.0	.90		51
		400	16	4.9	5.4	.91		38
		400	20	5.9	6.7	.88		31
		400	24	7.1	8.1	.88		25
		600	12	2.1	2.7	.85		76
		600	16	2.9	3.6	.81		57
		600	20	3.7	4.5	.82		46
		600	24	4.3	5.4	.80		38
		800	12	1.6	2.0	.80		102
		800	16	2.1	2.7	.78		76
		800	20	2.8	3.4	.82		61
		800	24	3.3	4.0	.83		51

Note: TDR's are different at different temperatures due to slight variations in disc hole dimensions

Temperature (°F)	AMVTSR
70	1.0
155	0.99
225	0.88
300	0.83

The change in AMVTR from 70-155°F is not significant, but has noticeable effect from that point on. The AMVTR then becomes the volumetric correction factor needed in calculating stack gas SO_2 concentration from the measured SO_2 concentration of the diluted stack gas. Stack SO_2 concentration is found from the following equation:

$$\text{Stack } SO_2 \text{ Conc. (ppm)} = \frac{\text{Measured } SO_2 \text{ Conc. (ppm)}}{\text{Volumetric Correction Factor (AMVTSR)}} \times \text{Theoretical Dilution Ratio}$$

The theoretical dilution ratios have been determined for each diluent flow and RPM by the following equation:

$$\text{Theoretical Dilution Ratio} = \frac{\text{Stack Chamber } SO_2 \text{ Conc. (ppm)}}{\text{Theoretical } SO_2 \text{ Conc. (ppm)}}$$

Assuming Complete Disc Hole Flushout

SO_2 concentrations in the stack simulation chamber have been measured by drawing off a sample of stack gas and transporting it to the Envirometrics SO_2 analyzer for measurement. Comparisons of the Envirometrics SO_2 analyzer, Shell SO_2-SO_3 method, and EPA Method 6 measurements of the same stack gas were made. The Shell and EPA Method 6 gave agreement to within 7% of the Envirometrics SO_2 measurement of 840 ppm for a 20 minute run. Long range agreement of the disc diluter measurements with EPA Method 6 have been made during field tests.

The theoretical SO_2 concentrations have been determined according to the calculation previously given. The first set of data (73°F) were determined with the orginal Delrin® disc which had a hole volume of 0.0656 cm^3. This disc became damaged and two more Delrin® discs were made. These two discs had slightly larger hold volumes of 0.0817 cm^3. These discs were used in the subsequent laboratory testing at 155, 225, and 300°F. This change does not affect results because the difference in volume is accounted for in the calculation of theoretical SO_2 concentration. The theoretical dilution ratios are, however, different due to the different disc hole volumes.

The maximum error to be expected in any stack SO_2 concentration determination can be found by using the extreme case deviation between measured versus theoretical SO_2 ratio and AMVTR. In Table 3 the extreme case deviation occurs at 225°F with the 12 RPM, 800 cc/minute value. The measured versus theoretical SO_2 ratio here is 0.79 and the AMVTR is 0.88 which is 10% deviation. The stack SO_2 concentration is calculated using the 1.5 ppm measured SO_2 value from the equation:

$$\text{Stack } SO_2 \text{ Conc. (ppm)} = \frac{1.5 \text{ ppm}}{0.88} \times 102$$

$$= 174 \text{ ppm}$$

$$\% \text{ Deviation from actual stack } SO_2 \text{ conc. (188 ppm)} =$$

$$\frac{188-174}{188} \times 100 = 7\%$$

The 7% maximum error to be expected in stack SO_2 determinations is quite good considering the large number of variables inherent in disc diluter operation and in stack conditions.

Determination of volumetric correction factors was also made for SO_2 calibration gases at various temperatures and the results are found in Table 4. The AMVTR are summarized as follows:

Temperature (°F)	AMVTR	Gas Sampled
75	0.98	SO_2
225	0.93	SO_2
300	0.86	SO_2
550	0.65	NO_x

It should be noted that the AMVTR value is somewhat different for the calibration gas and the stack gas. As indicated earlier, the AMVTR is near unity at low stack temperature whereas at high temperature the volume of stack gas delivered to the senser is less. As the calibration gas is initally at ambient temperature and is heated by the probe as it flows to the disc heater, the residence time under high stack temperature conditions is not sufficient for the gas to be heated to the stack temperature. As a result the calibration gas temperature is lower than the stack gas temperature and a higher AMVTR for the calibration gas results.

The SO_2 calibration gas concentration is already known, having been certified as such by the supplier. Therefore, SO_2 calibration gas concentrations calculated from the above equation should fall in a certain range of the certified value to indicate correct disc diluter operation prior to stack sampling. In the data presented, the extreme case of deviation for calculated and certified values occurs at 300°F with the 24 RPM, 200 cc/min. value. The measured versus theoretical SO_2 ratio deviates 0.10 from the AMVTR value of 0.86. Using the equation, the calculated SO_2 value is found from the measured SO_2 concentration of 13 ppm:

$$\text{Calculated SO2 conc. (ppm)} = \frac{13 \text{ ppm}}{0.86} \times 13$$

$$= 197 \text{ ppm}$$

Table 4. [illegible] Laboratory Testing Data - [illegible]

Plate Number Test	Fl.	SO_2 Analyzer # Set Point ppm	%	Effluent Flow cc/min.	RPM	%	SO_2 Conc. Measured of Diluted Cal. Gas ppm	Theoretical SO_2 Conc. Assuming Complete Dist from Fluidbed ppm	Measured vs. Theoretical SO_2 Ratio	Avg. % vs. Theoretical SO_2 Ratio	Calculated Efficiency
[illegible]				700	12		6.7	6.2	[illegible]	[illegible]	
				700	18		8.1	8.9	[illegible]		24
				600	20		11	12	[illegible]		14
				700	14		13	13	[illegible]		14
				400	12		3.4	3.2	[illegible]		14
				400	16		4.5	4.6	[illegible]		
				400	20		5.7	5.8	[illegible]		14
				400	24		6.5	6.7	[illegible]		14
				500	12		3.1	3.4	[illegible]		14
				500	16		3.8	3.8	[illegible]		14
				700	20		3.7	3.7	[illegible]		14
				700	24		4.4	4.5	[illegible]		14
				700	12		3.7	3.7	[illegible]		14
				800	16		4.1	4.1	[illegible]		14
				800	20		4.8	4.8	[illegible]		14
				700	24		5.1	5.1	[illegible]		14
[illegible]				700	12		7.2	6.5	[illegible]	[illegible]	
				1000	16		9.8	11	[illegible]		14
				1000	20		17	17	[illegible]		14
				1000	24		15	17	[illegible]		14
				400	12		3.9	4.2	[illegible]		
				400	16		5.4	5.6	[illegible]		
				400	20		6.8	6.9	[illegible]		
				400	24		8.1	8.3	[illegible]		
				500	12		2.5	2.8	[illegible]		
				500	16		3.4	3.7	[illegible]		14
				500	20		4.5	4.6	[illegible]		14
				500	24		5.4	5.5	[illegible]		14
				500	12		1.8	2.1	[illegible]		14
				500	16		2.5	2.8	[illegible]		14
				500	20		3.3	3.5	[illegible]		14
				500	24		4.0	4.2	[illegible]		14
[illegible]				700	12		6.8	9.0	[illegible]	[illegible]	
				1000	16		9.0	11	[illegible]		14
				1000	20		11	14	[illegible]		14
				1000	24		13	17	[illegible]		14
				400	12		3.6	4.2	[illegible]		14
				400	16		5.0	5.5	[illegible]		14
				400	20		6.4	6.9	[illegible]		14
				400	24		7.9	8.3	[illegible]		14
				500	12		2.5	2.8	[illegible]		14
				500	16		3.3	3.7	[illegible]		14
				500	20		4.0	4.6	[illegible]		14
				500	24		4.9	5.4	[illegible]		14
				500	12		1.9	2.1	[illegible]		14
				500	16		2.6	2.9	[illegible]		14
				500	20		3.4	3.7	[illegible]		14
				500	24		3.9	4.3	[illegible]		14
[illegible]				700	12		6.1	9.1	[illegible]	[illegible]	
[illegible]				1000	16		8.9	12	[illegible]		14
				1000	20		9.5	13	[illegible]		14
				1000	24		10	13	[illegible]		14
				400	12		3.8	4.6	[illegible]		14
				400	16		4.3	5.3	[illegible]		14
				400	20		5.1	7.4	[illegible]		14
				400	24		5.7	9.1	[illegible]		14
				500	12		2.1	3.0	[illegible]		14
				500	16		3.0	4.6	[illegible]		14
				500	20		3.6	5.1	[illegible]		14
				500	24		4.2	6.1	[illegible]		14
				600	12		1.5	2.3	[illegible]		
				600	16		1.8	3.0	[illegible]		
				600	20		2.2	3.8	[illegible]		
				600	24		2.0	4.8	[illegible]		

Note: [illegible] are different at different temperatures
Due to slight variation in dist hole dimensions

The percent deviation from the certified SO_2 concentration of the calibration gas is:

$$\frac{212-197}{212} \times 100 = 7\%$$

Thus in field sampling SO_2 calibration gas dilutions with the disc diluter should give calculated SO_2 calibration gas concentrations within 7% of the certified value. If the deviation is greater than 7% the disc diluter may be assumed to be improperly operating.

Curves of temperature versus volumetric correction factors for both stack gas and calibration gas are shown in Figures 11 and 12.

EFFECTS OF PARTICULATES

Before field testing began the effect of particulates on stack SO_2 dilutions was determined in the stack simulation test chamber. The work was performed with the complete disc diluter field assembly as shown in Figure 13. Previous work had shown that the disc diluter operated well in a high particulate environment. In order to determine any effect of particulates on SO_2 dilutions, the disc diluter was run at 24 RPM and 400 cc/minute diluent flow for 90 minutes in the stack simulation chamber. Particulate fly ash was fed in at a rate of 0.4 grains/cu. ft. The SO_2 analyzer was continously monitored to determine any change in SO_2 concentration of the diluted stack gas. No change in SO_2 reading due to the presence of particulates was observed during the 90 minute run. Therefore, SO_2 dilutions are not affected by the presence of particulates and no corrections will have to be made for them. In addition, the Delrin® disc cleaned itself very well during the 90 minute run. There was no accumulation of particulates between sealing surfaces that caused a leak of diluent air. Also, no visible particulates were present in the dilution chamber at the end of the run.

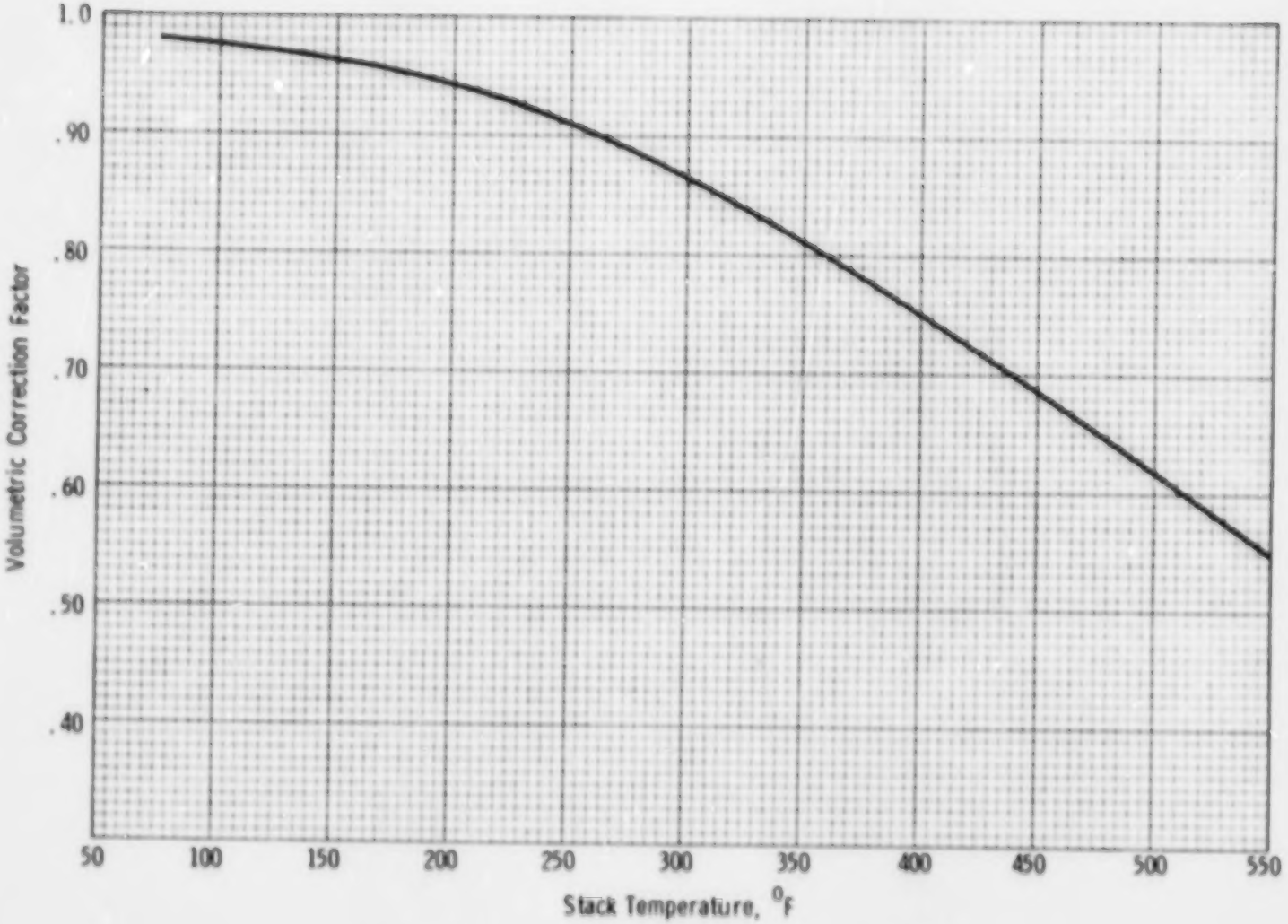


Figure 11. Calibration Gas VCF Curve

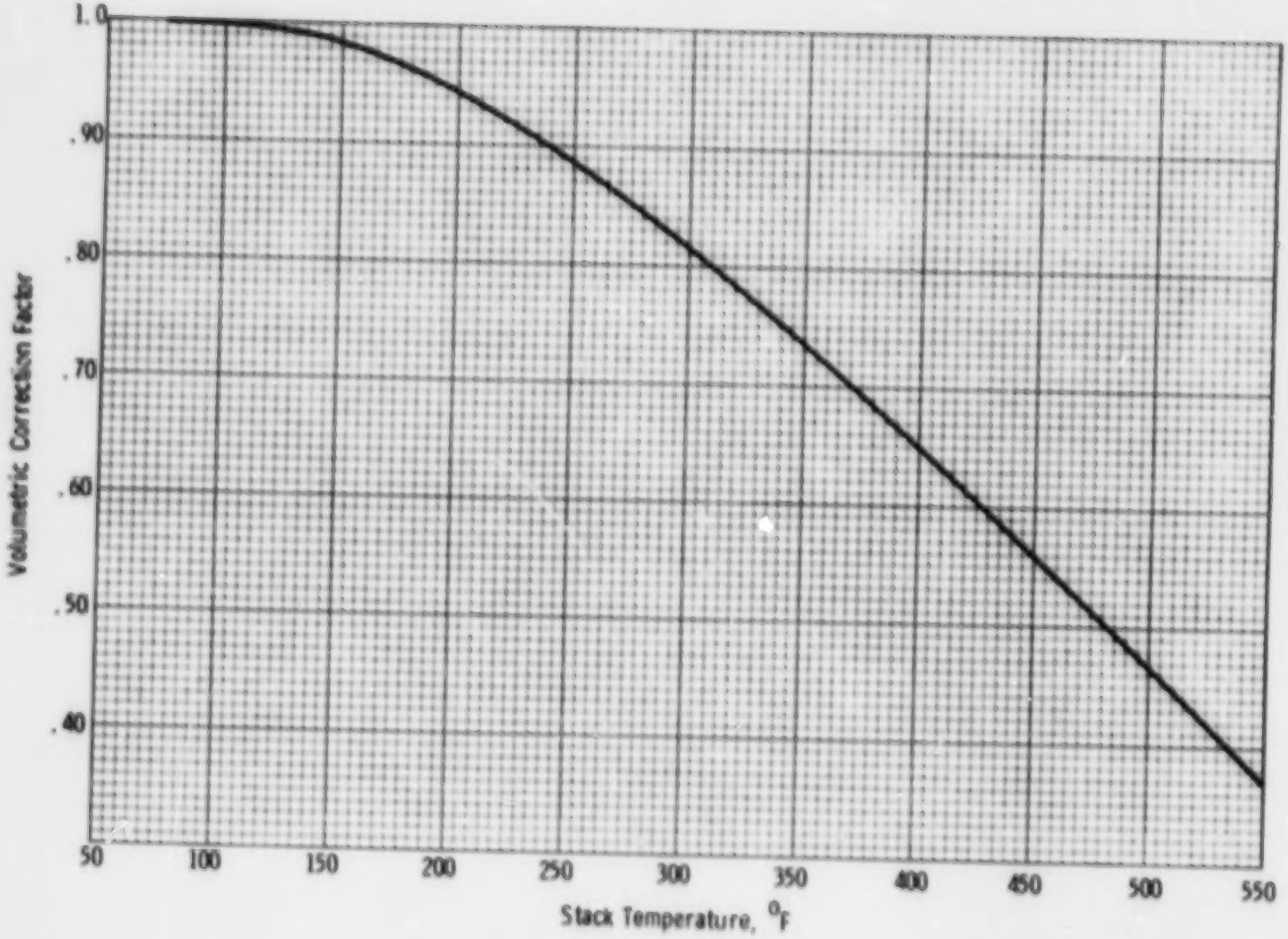


Figure 12. Stack Gas VCF Curve

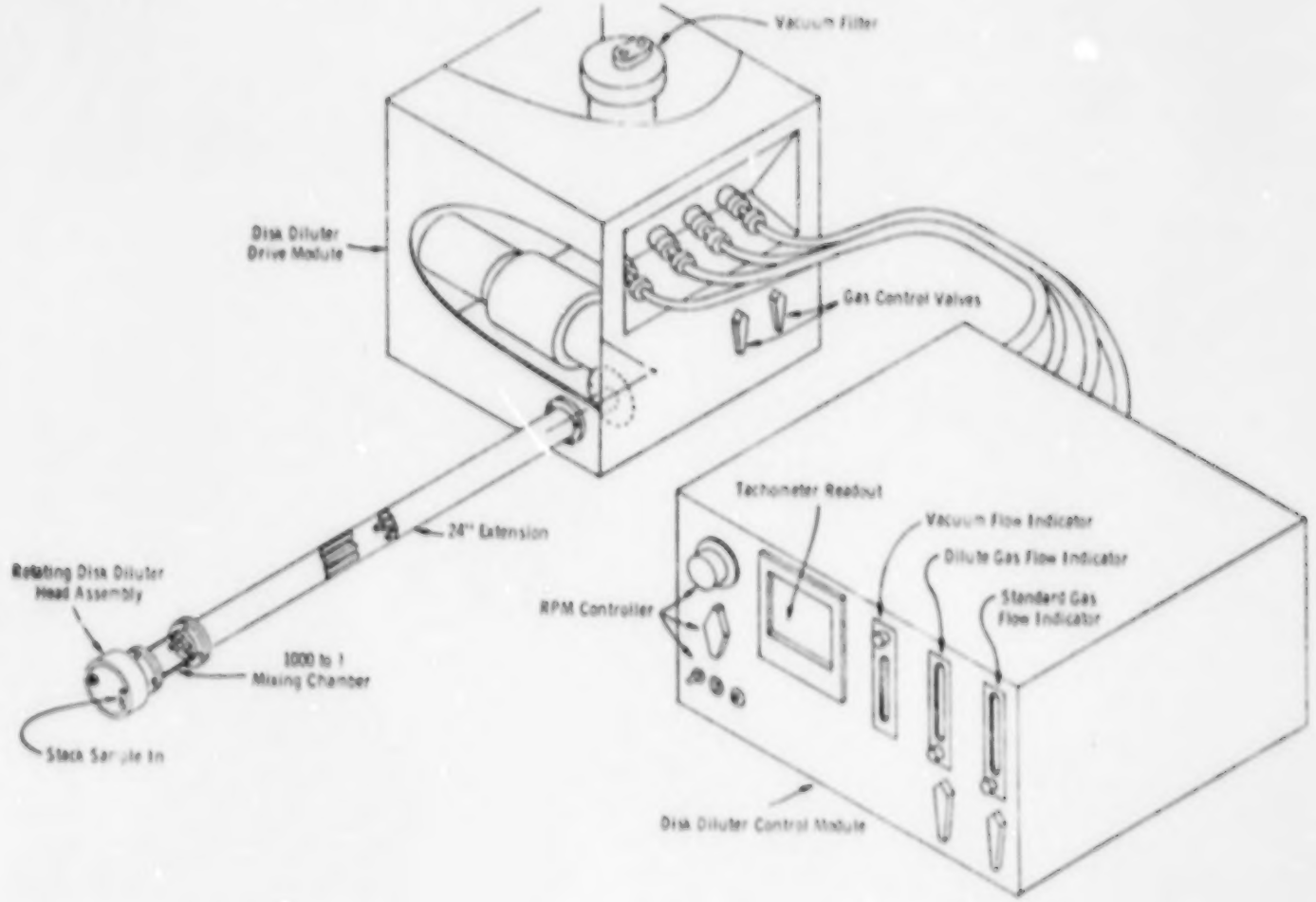


Figure 13. Disc Diluter Assembly for Field Sampling

SECTION VI

FIELD TESTING

Field sampling of the disc diluter was conducted at two sites. The first was a coal-fired steam boiler at the Dayton Power and Light Company's F. M. Tait Station. The other test was run on a gas-fired boiler at Monsanto Research Corporation's Dayton Laboratory. In the first test the sampling was for SO_2, while in the second test on the gas-fired boiler, sampling for NO_x was conducted. A description of the testing procedures and the results are included in this section.

FIELD TESTING AT DP&L COAL-FIRED BOILER

Field sampling at the Dayton Power and Light Company (DP&L) commenced during the third week of August, 1973. The stack sampled was from a coal-fired steam boiler used in the generation of electricity. The field sampling at this site was a critical test of the disc diluter because of the high temperature (~300°F) and high particulate fly ash content of the stack.

The disc diluter field assembly is shown in Figure 14 with the disc diluter head in the DP&L stack. For identification of components, refer to Figures 1 and 8. The EPA Method #6 sampling train is shown on the left in Figure 15. The digital thermocouple termometer for measuring stack temperature is shown in the middle with the disc diluter positioned on the right.

The disc diluter worked well mechanically and electrically over a wide range of operating conditions at the test site. Heavy particulate loadings and high ambient air temperatures resulted in adverse operation conditions. Ambient air temperatures ranged up to 110°F with no effect on the disc diluter operation. The very dusty working environment likewise had no effect on the disc diluter operation. The drive module was exposed to rain with no failure of the disc drive motor or other problem.

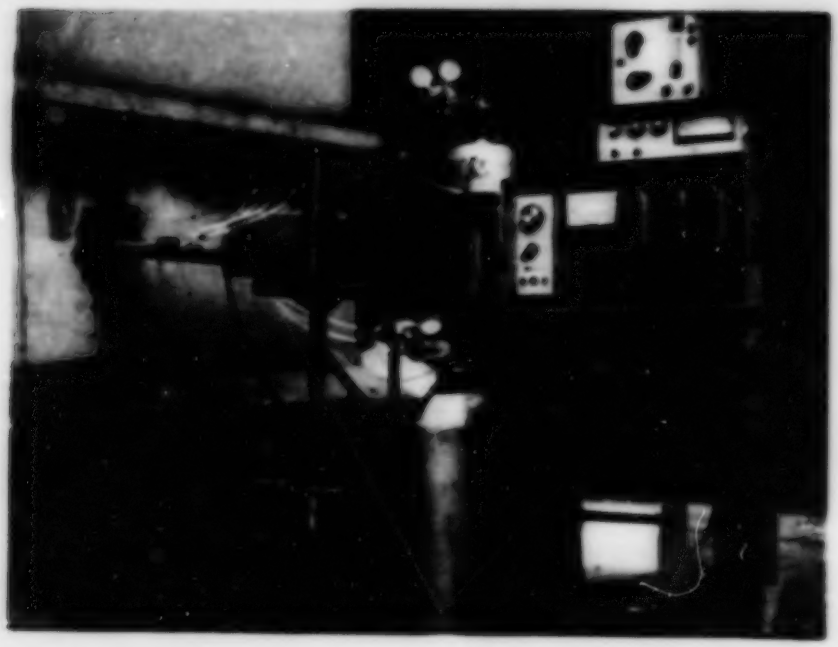


Figure 14. Disc Diluter Field Assembly at DP&L

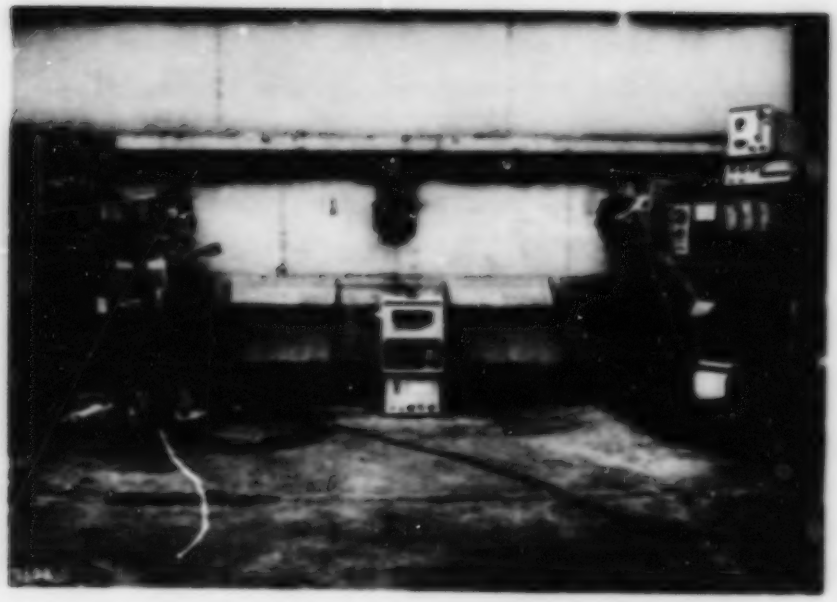


Figure 15. EPA Method 6 Sampling Train, Digital Thermometer, and Disc Diluter Field Assembly at DP&L

The particular test duct was before the induced draft fan and contained a very high particulate fly ash content which is typical of coal-fired electric utility burners. The disc diluter Delrin® disc cleaned itself very well and no problems occurred from particulate buildup in the disc diluter head. No significant accumulation of particulates occurred in the dilution chamber where the stack gas is diluted. The DP&L test site stack gas moisture content was about 3%. No condensation of moisture occurred downstream of the dilution chamber. Thus, the disc diluter has successfully eliminated particulate and moisture interferences from the measurement of SO_2 levels.

Condensation of moisture did occur in the vacuum line drawing stack gas into the disc head. This in no way affects disc diluter results. The vacuum filter (Figure 8) with its cellulose fiber filter and core of silica gel collects all the moisture and prevents condensation downstream of the drive module. The condensed moisture and particulates drawn into the vacuum line can be easily removed by flushing out with air. The diluent air switching valve (Figure 8) is turned to the down position sending diluent air out to the head through the vacuum line to remove particulates and condensed water.

The stack temperature of the DP&L test site depended in part on the outside ambient temperatures. On hot days the stack temperature exceeded 300°F by as much as 40°. Attempts to use the disc diluter over 300°F caused excessive vaporization of the Delrin® disc. A groove would develop in a circle connecting disc holes causing a leak in diluent air and consequently a drop in the measured SO_2 concentration of the diluted stack gas. The Delrin disc vaporized in the portion exposed to the stack. This phenomena occurs in temperatures lower than 300°F but to a much lesser extent. The disc vaporization did not affect results for the 30 minute run times at DP&L, but would be a limiting factor in long term operation in high temperature stacks.

Sampling at DP&L therefore was limited to days when the stack temperature was at or below 300°F. Also, coal burner shutdowns further hampered disc diluter testing.

The DP&L test site showed unusually high levels of NO_2 in the stack gas. Normally, in most combustion processes, the concentration of NO_2 is very low. Previous work at DP&L had indicated that the NO_x level was 50-80% of the SO_2 level. Normally NO_x is almost all NO in most combustion processes. The Envirometrics Paristor® SO_2 sensing element in the SO_2 analyzer showed a very large NO_2 interference in its measurement of SO_2, indicating that the NO_x present is mostly NO_2 rather than NO.

Mr. Michael Shaw of Envirometrics Inc., sent us a recently developed Paristor® SO_2 sensing element that shows a negligible NO_2 interference in SO_2 measurement even at high NO_2 concentrations. Accurate SO_2 measurements of the diluted stack gas concentrations could then be made.

The EPA Method 6 for stack SO_2 measurements was run concurrently with the disc diluter SO_2 measurements and was used as the standard of comparison for disc diluter results. Mr. Robert Keller, test and efficiency engineer at DP&L assured us that their previous pollution testing had shown that the stack gas was homogeneous across the stack. Both the Method 6 probe and disc diluter head were inserted into the stack gas to a depth of 15 inches. A run time of 30 minutes was selected for the simultaneous Method 6 and disc diluter runs.

The disc diluter SO_2 analyzer readings were recorded on a recorder for the 30 minute run. Chart paper readings at successive one minute intervals were averaged to give an average measured SO_2 reading for the diluted stack gas. The stack gas SO_2 concentration was then calculated according to the equation discussed previously using the appropriate volumetric correction factor and theoretical dilution ratio.

The results are shown in Table 5 for duplicate runs at DP&L. Both runs were performed with the original Delrin® disc which had a disc hole volume of 0.0656 cm^3. The results of the disc diluter show good agreement with the EPA Method 6.

Also, in-stack dilutions of 212 ppm SO_2 calibration gas was performed at the DP&L site and are also shown in Table 5. One of the results falls within the 7% maximum error figure found in laboratory testing but the other two do not. No explanation of this phenomena could be found since the disc diluter appeared to be working perfectly.

FIELD TESTING AT MRC GAS-FIRED BOILER

The disc diluter was tested on the Monsanto Research Corporation's gas-fired boilers. Since SO_2 levels were very low, the disc diluter was used to measure NO_x levels. The gas-fired boiler was operated at maximum capacity in order to test the performance of new Karak discs at temperatures over 300°F. Karak (Ohio Carbon Co.) is a carbon-graphite composite that can withstand 750°F, is chemically inert, and has excellent lubricity and wear characteristics. A disc of this material was fabricated and used in all field testing at this site. The Karak disc was rotated at 30 RPM for two hours in the boiler stack at 395-435°F. No wear or other deterioration of the disc was apparent after this test. Subsequent use of the disc diluter at temperatures up to 550°F did not have any deleterious effect on the Karak disc. The Karak disc therefore proved to be a good disc material for use in the disc diluter up to 550°F and it may be suitable for stack temperatures up to 700°F.

The disc diluter gas-fired sampling site is shown in Figure 16 with its stack extension and holes for inserting the disc diluter.

Table 5. Disc Diluter Field Testing Results at Dayton Power & Light Co.

In-Stack Dilutions of Stack Gas

Stack Temp. (°F)	Diluent Flow (cc/min)	RPM (R/S)	SO_2 Conc. Measured of Diluted Cal. Outlet Gas (ppm)	Volumetric Correction Factor	Theoretical Dilution Ratio (Old Disc)	Calculated SO_2 Stack Gas Cont (ppm)	EPA Method 6 SO_2 Conc (ppm)	Disc Diluter % Deviation from EPA Method 6
290-295	400	20	8.6	.83	38	394	420	8%
277	600	24	11.1	.85	48	627	655	4%

In-Stack Dilutions of SO_2 Calibration Gas

Stack Temp. (°F)	Diluent Flow (cc/min)	RPM (R/S)	SO_2 Conc. Measured of Diluted Cal. Outlet Gas (ppm)	Volumetric Correction Factor	Theoretical Dilution Ratio (New Disc)	Calculated SO_2 Calibration Gas Conc. (ppm)	Certified SO_2 Calibration Gas Conc. (ppm)	Disc Diluter % Deviation from Certified SO_2 Conc.
258-261	400	20	6.6	.90	31	227	212	7%
	600	24	6.0	.90	38	253	212	19%
	800	16	2.1	.90	76	177	212	17%

Figure 16. Dis Diluter at MRC Boiler Test Stack

For identification of components of the field assembly refer to Figure 13. The digital thermometer for measuring stack temperature is shown in the lower left corner. The disc diluter worked well mechanically and electrically at this site at ambient temperatures reaching down to 40°F. The stack particulate content was very low and consequently caused no problems with the disc diluter. The moisture content of the stack was about 18%.

As at DP&L no problems occurred from moisture condensation in the vacuum line drawing stack gas into the disc diluter. Condensed water was removed by flushing out the vacuum line with diluent air. Silica gel in the vacuum filter effectively prevented moisture from leaving the drive module. No interference occurred in the dilution of stack gas due to particulates or moisture. Since the stack simulation chamber used in the determination of volumetric correction factors had a temperature limitation of 300°F, it was necessary to determine the volumetric correction factor for the NO_x calibration gas at 550°F using the MRC boiler. The use of the boiler as a laboratory test chamber is permissable since temperature is the only variable affecting the dilution of calibration gas in this case. The volumetric correction factors for NO_x calibration gas are equally applicable to SO_2 as other pollutant calibration gas prepared in nitrogen. The volumetric correction factor data at 550°F is found along with the other volumetric correction factor data in Table 4 and is plotted in the curve in Figure 11.

The disc diluter was inserted into the MRC boiler stack for one hour to allow the disc diluter head assembly to reach stack temperature. The Envirometrics analyzer was fitted with an NO_x sensor (N76H3) and calibrated with a 302 ppm NO_x calibration gas which was 99% NO and 1% NO_2. The disc diluter was operated at 24 RPM and 200 cc/minute diluent flow for all tests.

When a reading was taken of the NO_x concentration of the diluted stack gas, the stack was sampled immediately using the EPA Method 7 for NO_x. Since the EPA Method 7 is not a continuous sampling method only instaneous comparisons of the stack NO_x levels with this method and the disc diluter could be made. The results of four NO_x comparisons are shown in Table 6, in the consecutive order that they were made.

Also shown in Table 6 are the results for in-stack dilutions of NO_x calibration gas. NO_x calibration gas determination was made prior to a stack gas determination. The order shown in the table is the order in which dilutions of NO_x calibration and stack gas were made, i.e. the first calibration gas value was determined before the first stack gas value and so on.

Both the stack gas and calibration gas determinations were made using the equation discussed previously.

$$CS = \frac{(MC_s)\ (TDR)}{(VCP)}$$

The volumetric dilution factors were found from the curves in Figures 11 and 12.

The disc diluter NO_x stack gas dilutions in Table 6 show greater deviation from the EPA comparison method than was the case with the SO_2 results found at DP&L. Also, the calculated NO_x calibration gas results show a greater deviation from the certified NO_x calibration gas concentration (302 ppm). The disc diluter appeared to be working perfectly and no explanation can be seen for why the difference between calculated and certified NO_x values. It may be necessary to use the following correction.

$$\frac{\text{Calculated } NO_x \text{ cal. gas conc.}}{\text{Certified } NO_x \text{ cal. gas conc.}} \times \text{Calculated } NO_x \text{ Stack Gas Conc.} = \text{Corrected } NO_x \text{ Stack Gas Conc. (ppm)}$$

Table 6. Disc Diluter Results at Monsanto Research Corporation

In-Stack Dilution of Stack Gas

Stack Temp. (°F)	Diluent Flow (cc/min)	RPM (±25)	NO_x Conc. Measured of Diluted Stack Gas (ppm)	Volumetric Correction Factor	Theoretical Dilution Ratio	Calculated NO_x Stack Gas Conc. (ppm)	EPA Method 7 NO_x Conc. (ppm)
535-550	200	24	2.1	0.37	16	104	67
	200	24	2.4	0.37	16	91	77
	200	24	2.9	0.37	16	125	77
	200	24	2.7	0.37	16	117	69

In-Stack Dilution of Calibration Gas

Stack Temp. (°F)	Diluent Flow (cc/min)	RPM (±25)	NO_x Conc. Measured of Diluted Cal. Outlet Gas (ppm)	Volumetric Correction Factor	Theoretical Dilution Ratio	Calculated NO_x Cal. Gas Conc. (ppm)	Certified NO_x Cal. Gas Conc. (ppm)
535-550	200	24	9.1	0.65	16	224	302
	200	24	9.1	0.65	16	224	302
	200	24	8.8	0.65	16	217	302
	200	24	9.1	0.65	16	224	302

The use of this correction brings the stack gas data in Table 6 more in line with the EPA Method 7 measurements. The use of such a correction is suggested in the DP&L data where such a correction would bring the stack SO_2 determinations more in line with the Method 6 SO_2 determinations.

SECTION VII

DISCUSSION OF RESULTS

The commercial prototype disc diluter has been designed and constructed, laboratory tested, and field tested. A few basic design changes have been made since the original research prototype was developed. An airtight housing was constructed for the diluter head to help prevent leakage. For stack temperatures up to 300°F, the original Teflon disc was replaced by one made of Delrin® to reduce the wear and increase the lifetime of the disc.

The laboratory testing was an extensive investigation into the operating parameters of the disc diluter. Calibration of the equipment was performed in a controlled atmosphere where numerous variables could be adjusted. The preliminary work done in the laboratory was to locate and correct any possible problems involved with the operation of the disc diluter. All major changes were made in the laboratory so that the field testing and data collection could be done in a more efficient manner.

During the laboratory testing the equipment was checked to see if all parts functioned properly. The accuracy of the disc diluter results could be verified in the controlled atmosphere of the simulation chamber. The efficiency of the disc diluter head assembly as a collection device was examined. The leakage of gas due to the wear of the disc material was corrected by using the different material. The incomplete flushout problem was eliminated by a small change in the design of the dilution chamber. The flow of the diluent gas stream was diverted slightly so that optimum mixing would occur in the dilution chamber. The speed at which the disc rotated was coordinated with the volume of holes in the disc and the flowrate of diluent gas to give the actual sampling rate and the dilution ratio.

Preceding page blank

Tests were run to compare the actual measured SO_2 reading with the theoretical SO_2 value. The SO_2 concentration measured in the diluted sample inlet gas was usually less than the theoretical SO_2 concentration assuming complete disc hole flushout. This was particularly true at the higher temperatures at which some tests were conducted. Both stack gas and calibration gas tests indicated the SO_2 concentration difference. These results have led to the use of a volumetric correction factor when calculating SO_2 concentrations.

Since the samples collected in the stack are at stack temperature, they will cool to ambient air temperatures as they are being analyzed by the ambient air monitors. A reduction in volume of the gas collected in the disc hole as it moves through the diluter is caused by this cooling. Therefore, as the temperature of the stack gas increases, there is a larger change in volume of the stack gas. A ratio of the actual measured SO_2 concentration to the theoretical measured SO_2 concentration has been used to compare values. As the temperature of the stack increases, the ratio decreases since the stack gas represents a smaller portion of the total volume being tested by the ambient air monitors.

To obtain the stack SO_2 concentration, the measured concentration must be divided by the changing volume ratio. Graphs of both calibration and stack gas volumetric correction factor curves are located in Section IV.

The final laboratory test involved determining the effects of high particulate concentrations in the stack gas stream. The particulate was continuously fed into the simulation chamber and dispersed throughout the gas. The results during this test were no different than those run without particulate matter in the gas stream. No visible wear was evident on the disc and no build-up of particulate was observed around the dilution chamber.

After completing the extensive laboratory testing program, the disc diluter was field tested in order to determine if there would be any change in its efficiency due to the conditions in the field. Two boilers were tested with one being a coal-fired unit and the other a gas-fired unit. The capabilities of measuring SO_2 concentrations were tested with the use of the stack gas from the coal-fired unit while NO_x concentrations were measured in the stack gas from the gas-fired boiler.

Under the severe operating conditions at the Dayton Power and Light Company where the coal-fired unit was located the disc diluter performed well. The ambient temperatures ranged up to 100°F and the environment was dusty. No major problems developed in the operation of any equipment.

One of the difficulties encountered was the high temperature of the stack gases. Delrin® begins to degrade around 325°F and, since the stack gas temperature exceeded 300°F, excessive vaporization of the disc occurred. Further sampling was performed only on days when stack gas temperatures were less than 300°F.

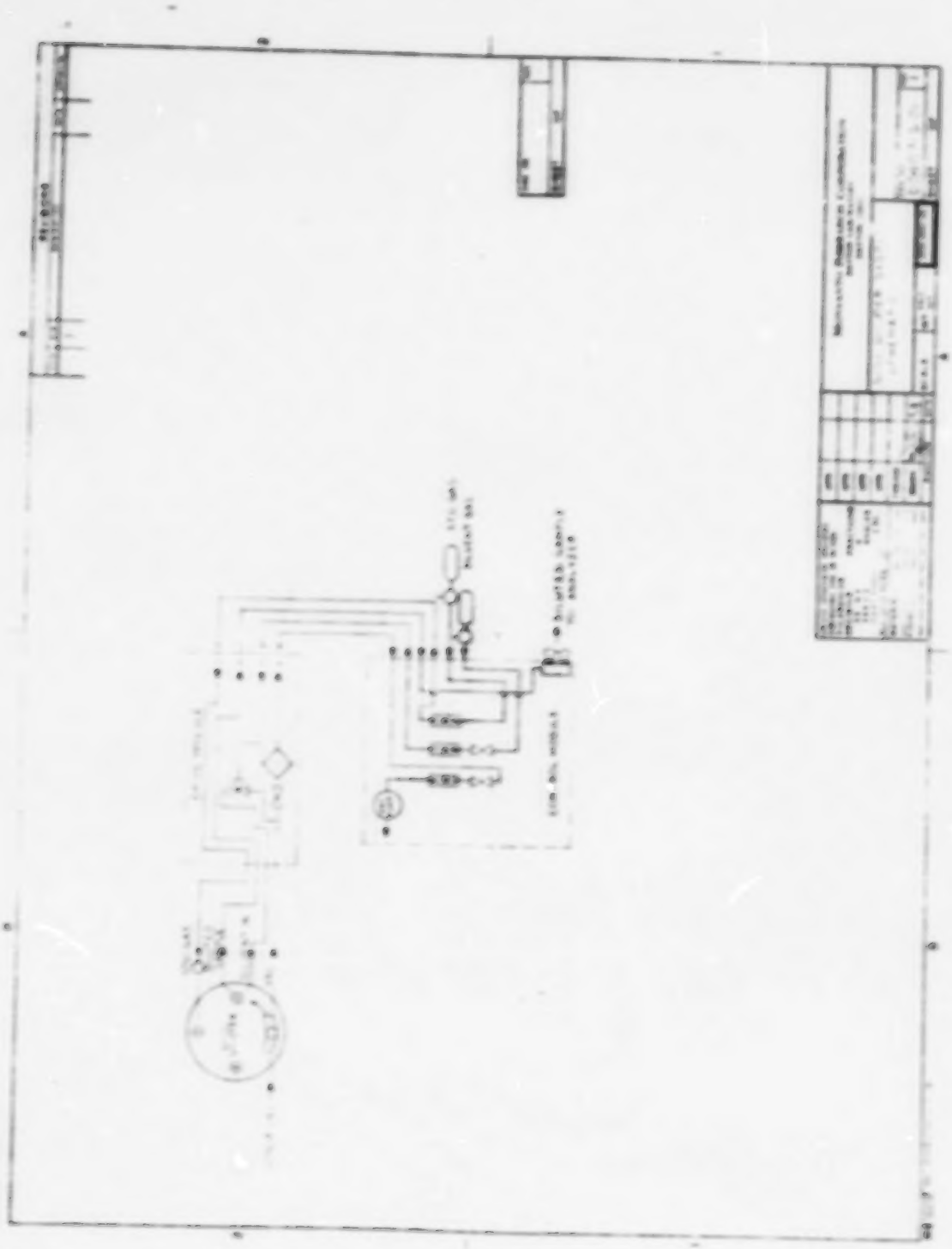
EPA Method 6 and the disc diluter were run simultaneously to compare results. On two comparison runs, the deviation between the two methods was 8% and 4%, with Method 6 giving the higher concentration readings in both runs. The volumetric correction factor was used in calculating the SO_2 concentration collected with the disc diluter.

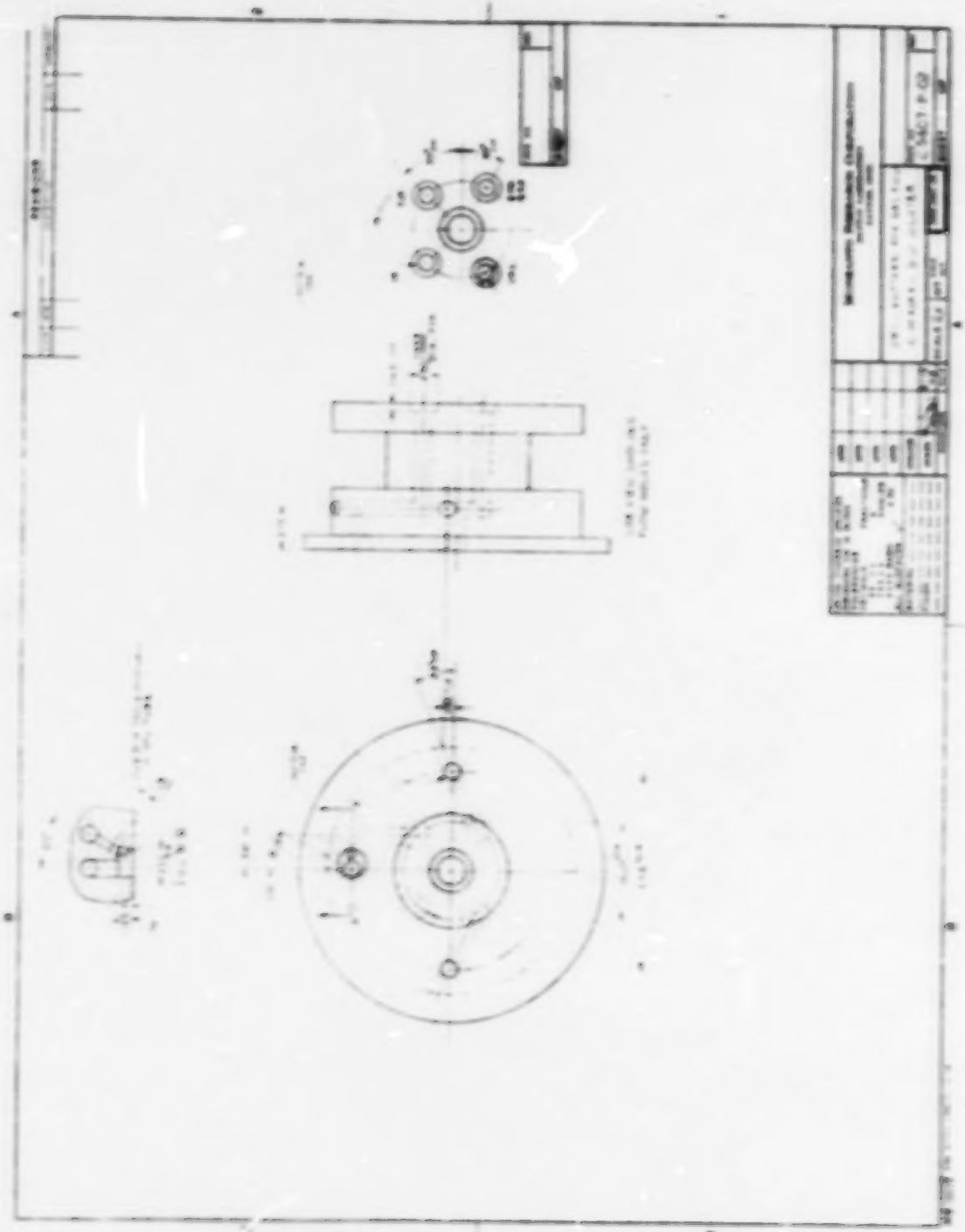
At Monsanto Research Corporation's gas-fired boiler, NO_x levels were measured. In order to withstand the higher stack temperatures of the boiler, a new disc material was used. A carbon-graphite composite called Karak (Ohio Carbon Co.) which is chemically inert and can withstand temperatures up to 750°F was used. Stack gas temperatures up to 550°F had no apparent deleterious effect on the Karak disc.

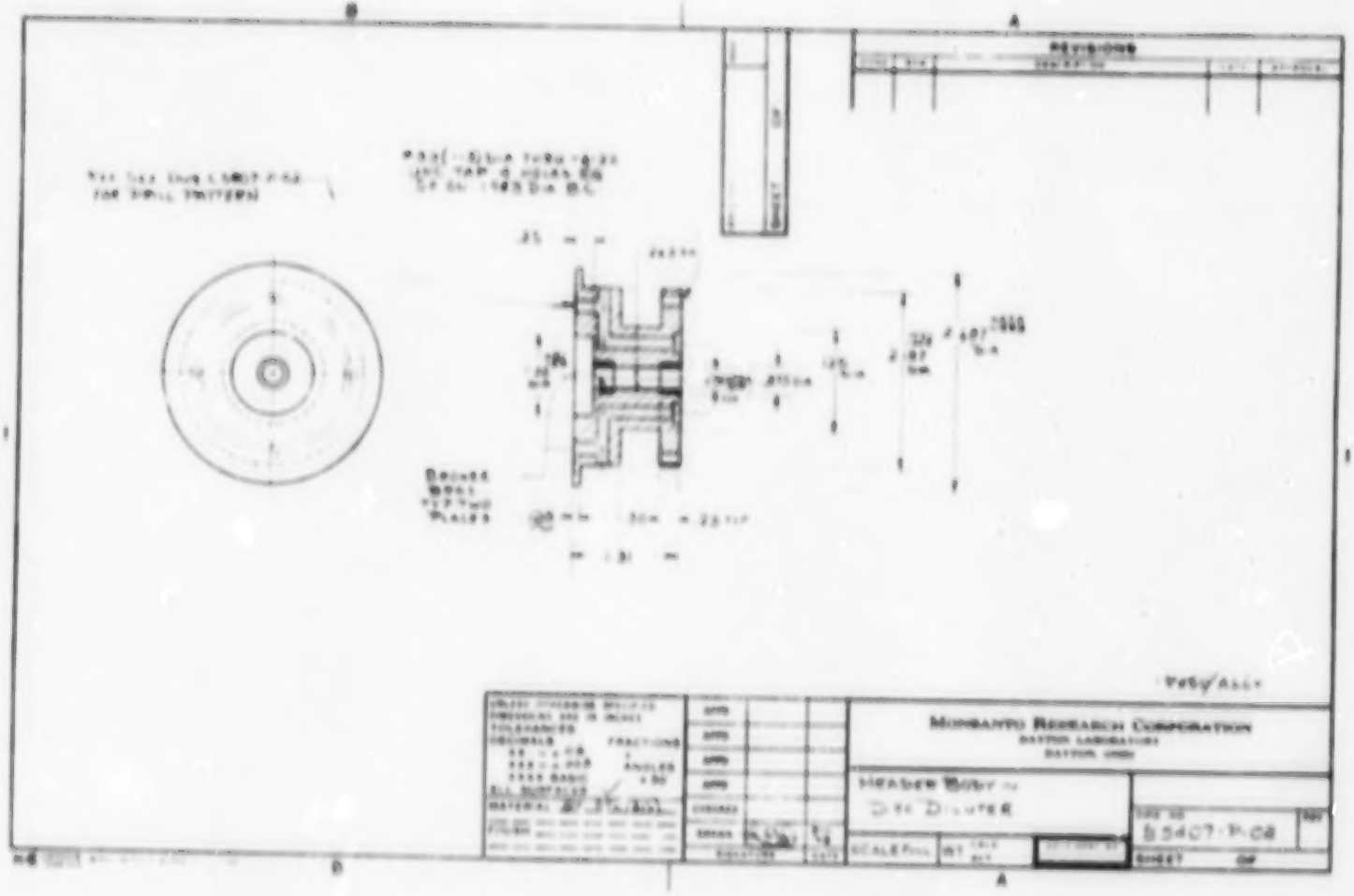
The Enviroметrics analyzer previously used was fitted with an NO_x sensor and used for this field testing. EPA Method 7 was used as a comparison test for NO_x. Since Method 7 is not a continuous sampling method, only instantaneous measurements of the stack NO_x levels were made. Four comparison runs were performed. The results varied considerably. The disc diluter results were much higher than those from Method 7. The maximum difference was 41% less. The different types of sampling tests may have resulted in some of the difference.

In summary, the laboratory tests showed the disc diluter could function properly in a controlled atmosphere. The field testing results for SO_2 from the coal-fired boiler compared favorable with those found using EPA Method 6. However, the NO_x results did not compare well with those of EPA Method 7. Further tests should be run to give a better idea of the performance of the disc diluter.

APPENDIX A

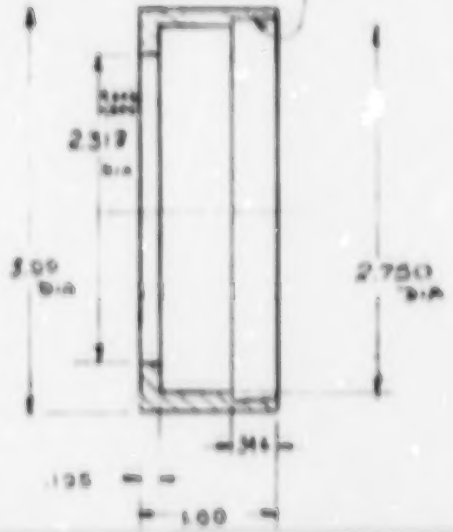





MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO
DRAWING NUMBER
B5407-P-C8
SCALE FULL

60a

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVAL



1 REQD/ASSY

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS FRACTIONS
XX = ± .01 ±
XXX = ± .005 ANGLES
XXXX BASIC ± 30'
ALL SURFACES

MATERIAL
FINISH

APPD			
APPD			
APPD			
APPD			
CHECKED			
DRAWN			8-7 72
	SIGNATURE		DATE

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO

Header Assy Holding Ring - Disc Diluter

SCALE Full | WT CALC ACT | CODE IDENT NO

DWG NO. A5407-P-03 | REV

SHEET OF

REVISIONS				
ZONE	BTR	DESCRIPTION	DATE	APPROVAL

DWG NO

.13 DIA
4 PLACES
AS SHOWN

2.875-20 UN-2A THD

2.741
MAX. P.D.

2.30
B.C.

2.187
DIA

.13

.250

1 REQ'D/ASS'Y

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS
.XX = ±.02
.XXX = ±.005
.XXXX BASIC
ALL SURFACES
FRACTIONS ±
ANGLES ±30'

MATERIAL 316 S.S.

FINISH

APPD			
APPD			
APPD			
APPD			
CHECKED			
DRAWN		8-7	
SIGNATURE		DATE	

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO

THD CLAMP RING FOR HEADER ASS'Y DISC DILUTER

DWG NO A5407-P-04

REV

SCALE 1/2 WT CALC ACT.

CODE IDENT NO

SHEET OF

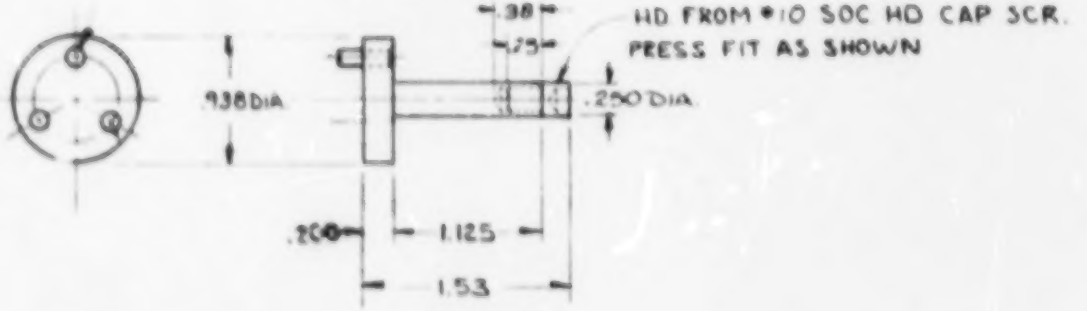
K-E

19

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVAL

DWG. NO.

.13 DIA X .38 LG PINS
3 PLACES EQ SP ON
.625 DIA B.C.



6/a

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES				
TOLERANCES				
DECIMALS	FRACTIONS			
XX = ±.02	±			
XXX = ±.005	ANGLES			
XXXX BASIC	±30			
ALL SURFACES				
MATERIAL		APPD		
		APPD		
		APPD		
		APPD		
FINISH		CHECKED		
		DRAWN		3-13-79
		SIGNATURE		DATE

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO

DRIVE ROTOR ~ DISC DILUTER

SCALE Full	WT CALC ACT	CODE IDENT NO

DWG NO A 5407-P-05 REV

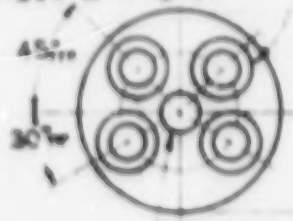
SHEET OF

H-E

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVAL

DWG. NO.

MACH. FOR SLIP FIT
WITH .250 OD X .049
WALL TUBE FOR WELD
LATER AT ASS'Y.
.481 DIA X .050 DP C'BORE
4 PLACES AS SHOWN
ON .860 D.I.A. B.C.



.265 DIA.

NOTE
OD. TO BE MACH FOR .0005 PRESS
FIT WITH I.D. OF 1¼ SCHD 5
S. STL. PIPE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES DECIMALS: XX = ±.01, XXX = ±.005, XXXX BASIC FRACTIONS ± ANGLES ±30' ALL SURFACES ✓	APPD		
	APPD		
	APPD		
	APPD		
MATERIAL	CHECKED		
FINISH	DRAWN		
	SIGNATURE		DATE

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO

FLG. GAS TUBE END ~
DISC DILUTER

DWG NO. A5407-P-06 REV

SCALE Full WT CALC ACT

SHEET OF

K+E

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVAL

(SEE TABLE) THRU
4 PLACES EQ SP
ON 1.968 DIA BC.

DIM A	REQ'D	156 DIA THRU
DIM B	REQ'D	*33(113) DIA THRU ~ 6-32 TAP THRU

NOTE
MACH. FOR LIGHT PRESS
FIT WITH OD OF 1¼ SCHD 5
PIPE, TO BE WELDED

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS
XX = ±.02
XXX = ±.005
XXXX BASIC
FRACTIONS ±
ANGLES ± 30'
ALL SURFACES √

MATERIAL
FINISH

APPD			
APPD			
APPD			
APPD			
CHECKED			
DRAWN		3-15-73	
	SIGNATURE	DATE	

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO

FLANGE, COUPLING ~
DISC DILUTER

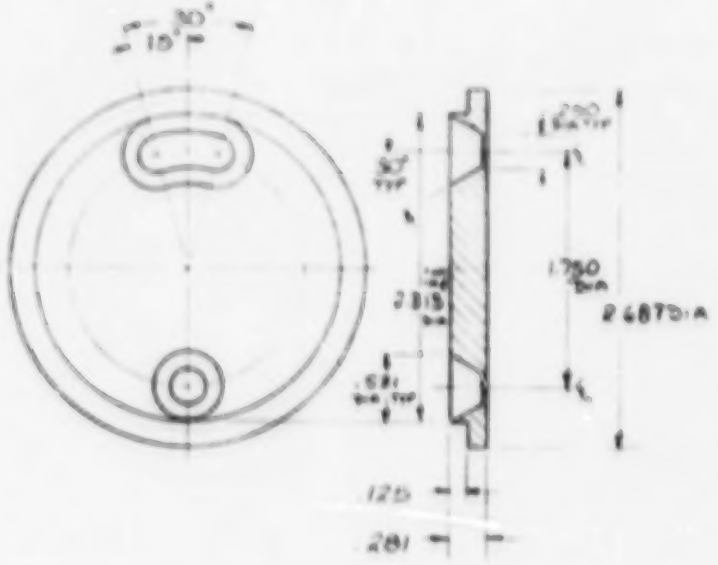
SCALE Full | WT CALC | EQUIPMENT NO

DWG NO A5407-P-07 | REV

SHEET OF

62a

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVAL



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES DECIMALS .XX = ±.03 FRACTIONS ± .XXX = ±.005 ANGLES ±30' .XXXX BASIC ALL SURFACES ✓	APPD		
	APPD		
	APPD		
	APPD		
MATERIAL 316 S.S.	CHECKED		
FINISH	DRAWN		5-13-73
	SIGNATURE		DATE

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO

GAS ENTRY D SC
DISC DILUTER

DWG NO. A5407-P-08 REV

SCALE Full WT CALC ACT

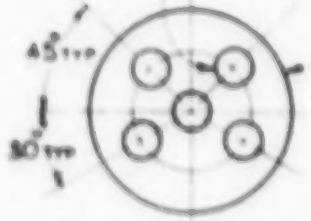
CODE IDENT NO.

SHEET OF

63

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVAL

.27 DIA THRU
5 PLACES
ON .860 DIA
B.C.



MACH. FOR .001 PRESS FIT
WITH I.D. OF 1¼ SCHD 5
S.STL. PIPE ~ THICKNESS
.25

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS
.XX = ±.03
.XXX = ±.005
.XXXX BASIC
ALL SURFACES
FRACTIONS
±
ANGLES
±30'

MATERIAL TEFLON
FINISH

APPD			
APPD			
APPD			
APPD			
CHECKED			
DRAWN		8-14-79	
	SIGNATURE	DATE	

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO

TEFLON SPACERS ~
DISC DILUTER

DWG NO A-5407-P-09
REV

SCALE 1/1 | WT CALC ACT | DOES NOT NO

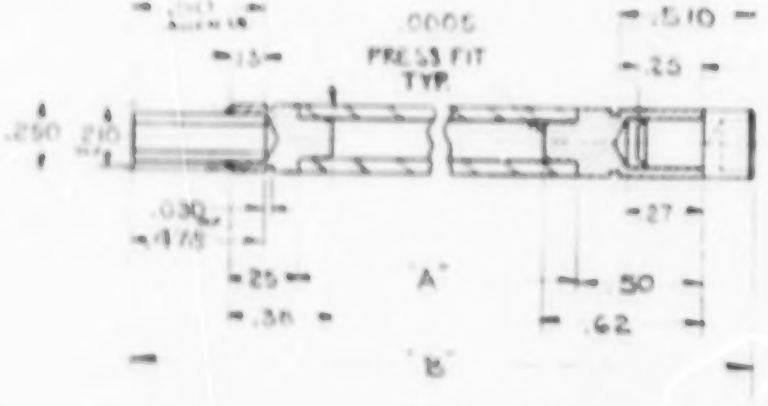
SHEET OF

H-B

630

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVAL

.250 OD X .069 WALL
316 S STL TUBE



ITEM NO	B DIM	A DIM
4	60.135	58.823
3	48.135	46.823
2	36.135	34.823
1	24.135	22.823

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS
XX = ± .03
XXX = ± .005
XXXX BASIC
FRACTIONS ±
ANGLES ± 30'
ALL SURFACES

MATERIAL 316 S STL
FINISH

APPD		
APPD		
APPD		
APPD		
CHECKED		
DRAWN		3-15-79
SIGNATURES		DATE

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO

DRIVE SHAFT ~
DISC DILUTER

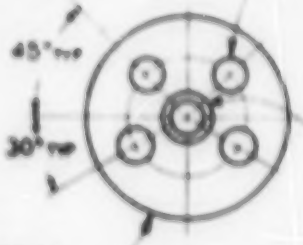
SCALE 2X | WT CALC ACT | DOCUMENT NO

DWG NO. A5407-P-10 | REV

SHEET OF

REVISIONS				
ZONE	BTM	DESCRIPTION	DATE	APPROVAL

MACH. FOR SLIP-FIT WITH OD OF .250 OD X .049 WALL TUBE ON .860 DIA. B.C



MACH. FOR .0005 PRESS FIT WITH I.D. OF 1¼ SCHD 5 S STL. PIPE PIECE .250 THICK

.375 OD X .250 ID. BRONZE BRG.

64a

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS
.XX = ±.03
.XXX = ±.005
.XXXX BASIC
FRACTIONS ±
ANGLES ±30'
ALL SURFACES

MATERIAL
FINISH

APPD			
APPD			
APPD			
APPD			
CHECKED			
DRAWN		8-13-69	
SIGNATURE		DATE	

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO

FLANGE DISC DILUTER

DWG NO. A5407-P-11 REV

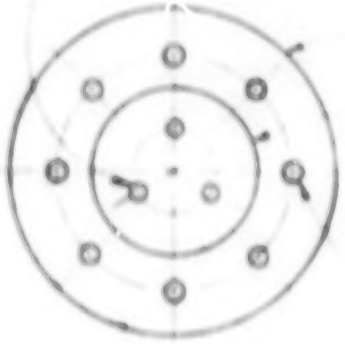
SCALE Full WT CALC ACT

SHEET OF

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVAL

DWG NO

.500
.495
.180 DIA THRU
3 HOLES EQ SP
ON .625 DIA B C



2.50 DIA X .240 THICK

1.25 DIA X .13 DP
UNDERCUT

.141 DIA THRU
6 PLACES EQ SP
ON 1.75 DIA BC

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS
.XX = ±.02
.XXX = ±.005
.XXXX BASIC
FRACTIONS ±
ANGLES ± 30'
ALL SURFACES √

MATERIAL Kel-F
FINISH

APPD			
APPD			
APPD			
APPD			
CHECKED			
DRAWN		3-15-72	
SIGNATURE		DATE	

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO

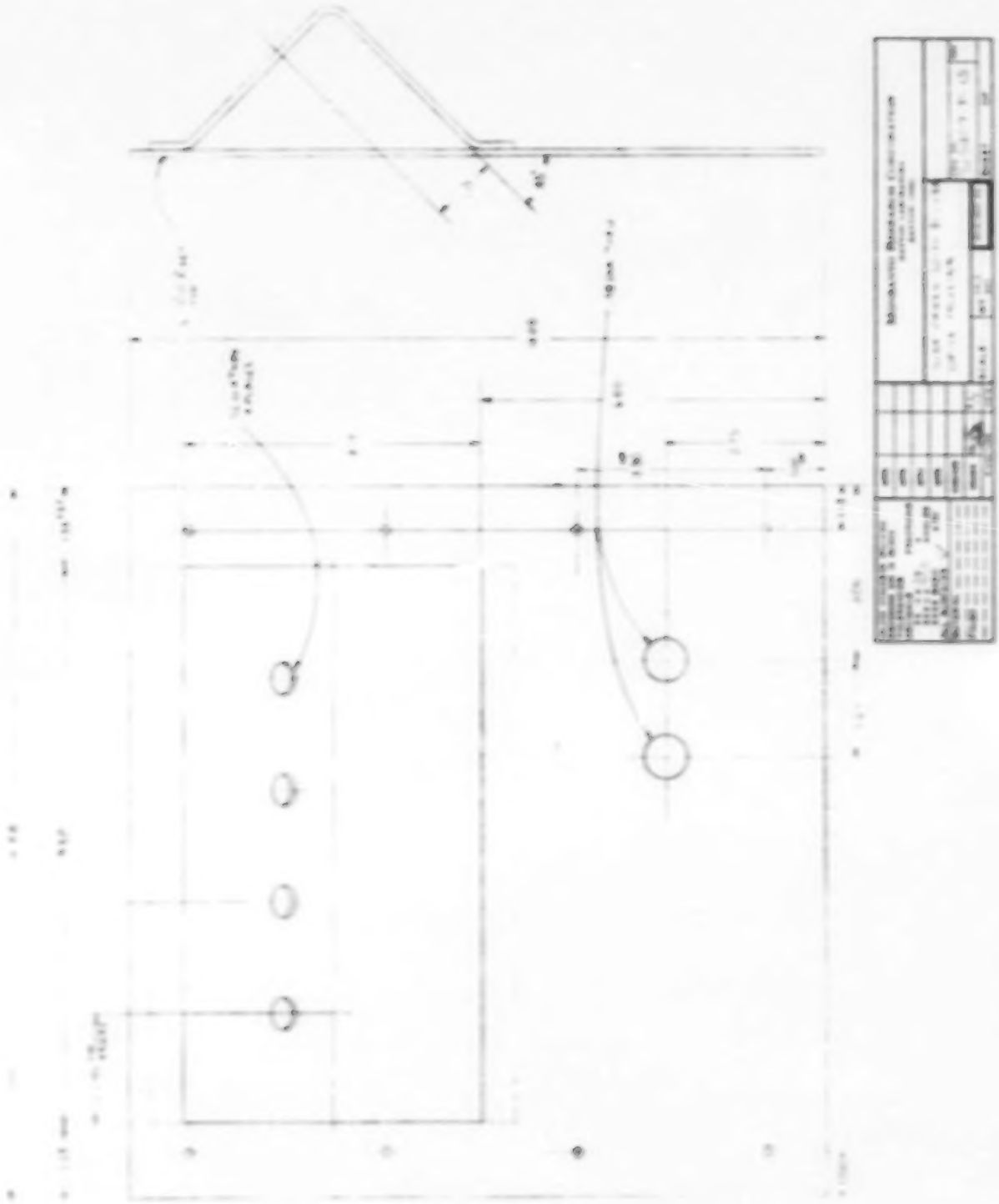
ROTATING DISC
- DISC DILUTER

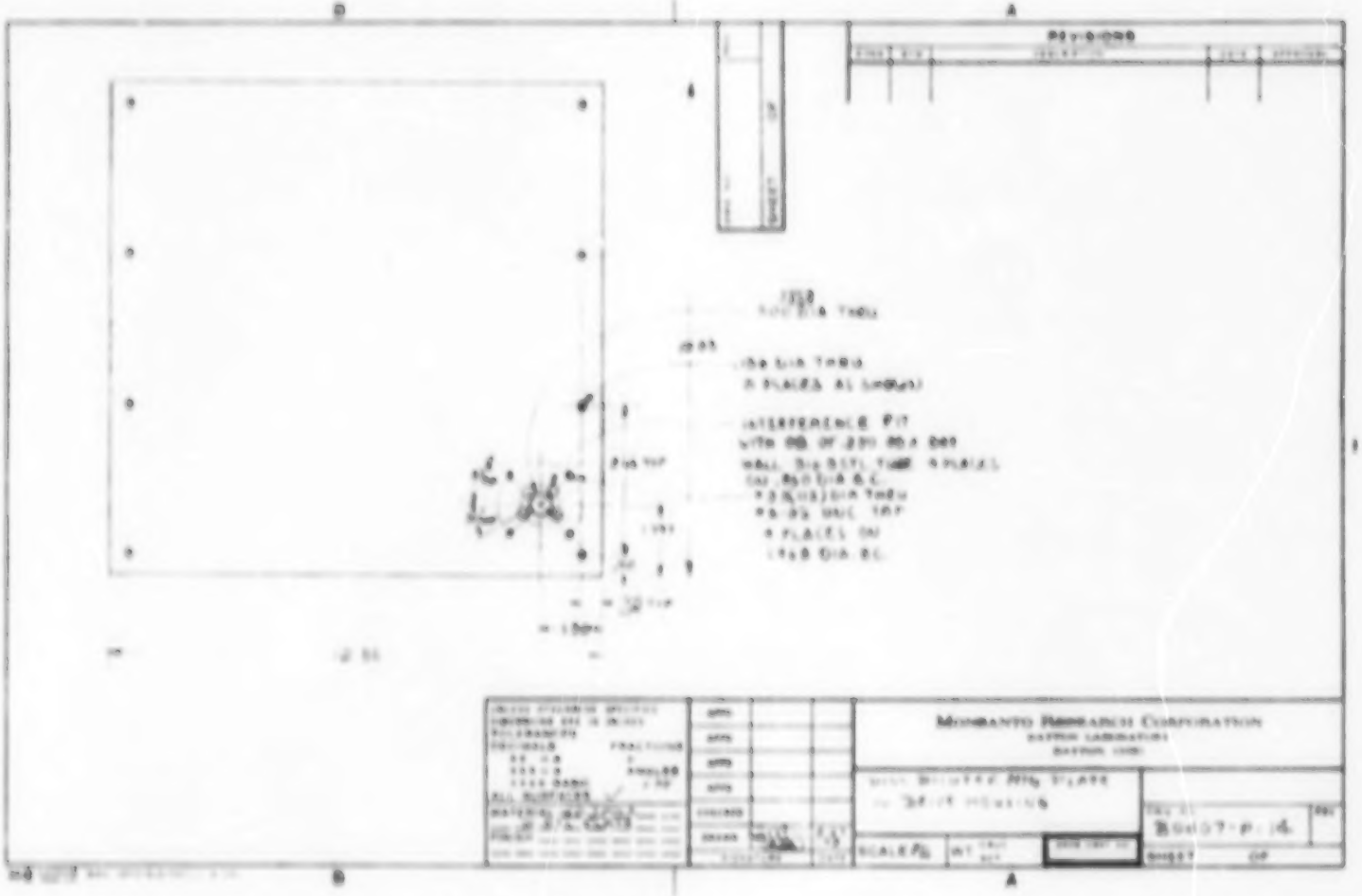
DRG NO A5407-P-12

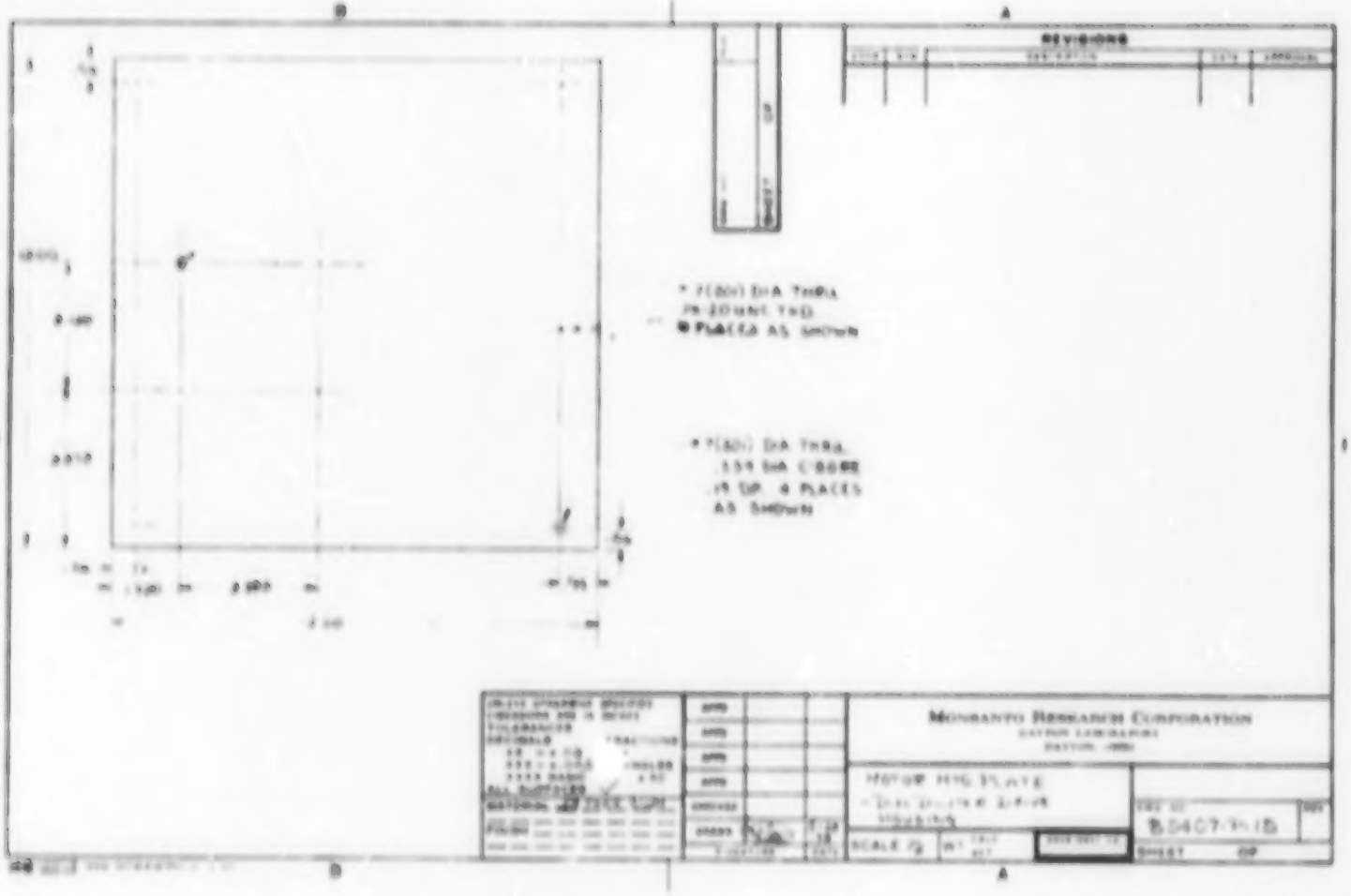
REV

SCALE Full WT CALC ACT

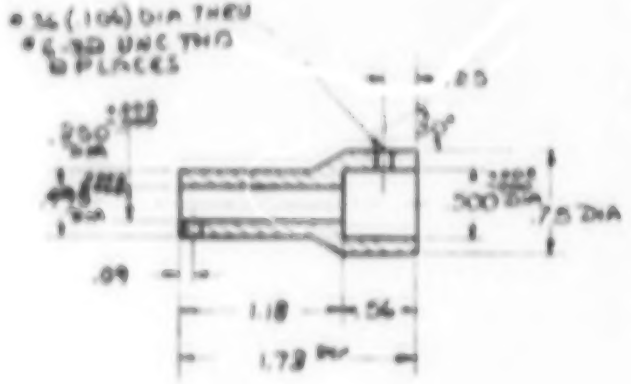
SHEET OF






REVISIONS
MONSANTO RESEARCH CORPORATION

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVAL



UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS
XX ± 0.03
XXX ± 0.005
XXXX BASIC
FRACTIONS ±
ANGLES ± 30'
ALL SURFACES
MATERIAL SS 316 Ti
FINISH

APPD			
APPD			
APPD			
APPD			
CHECKED			
DRAWN		8-29-73	
	SIGNATURE	DATE	

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO

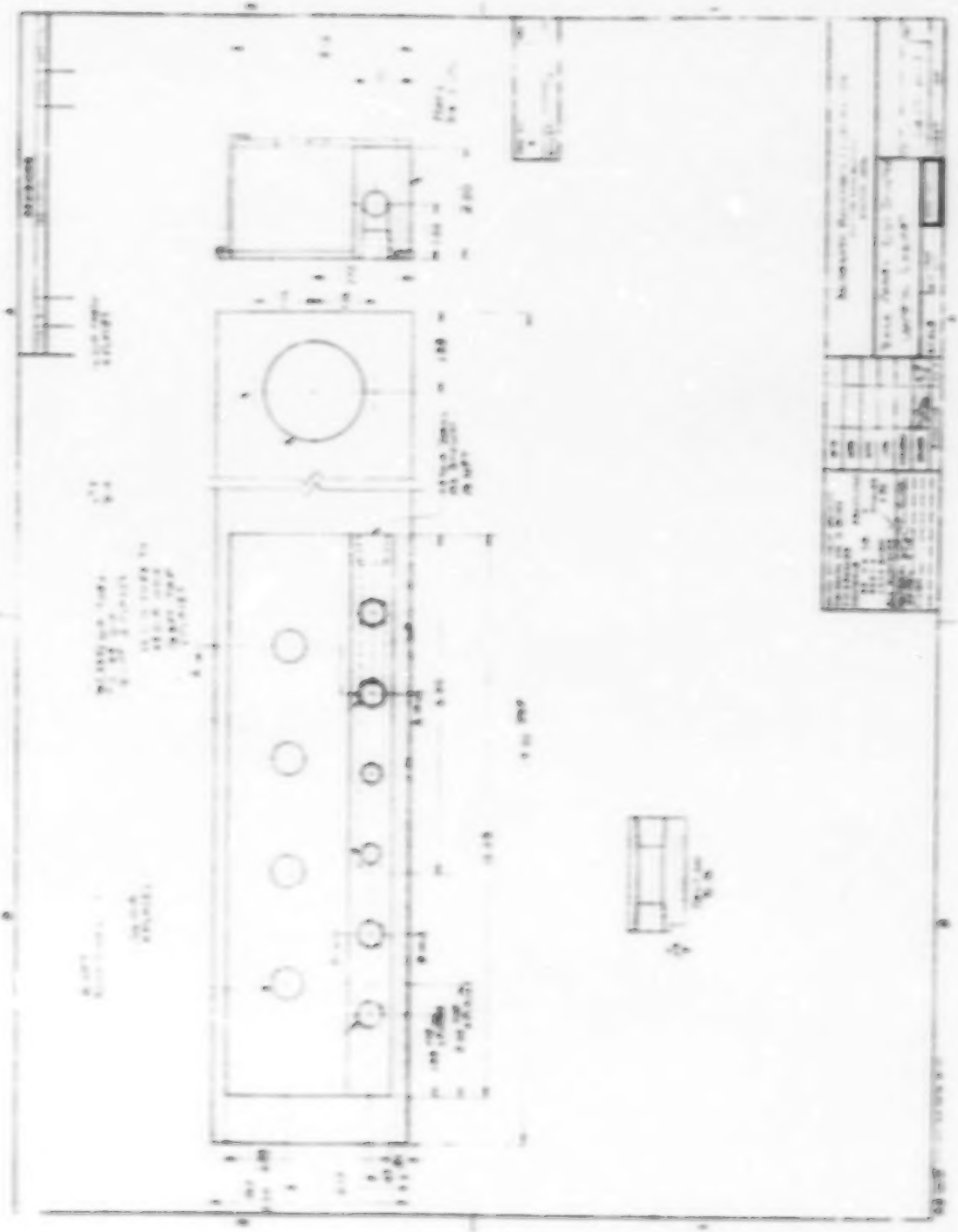
MOTOR - DISC DILUTER TRAIN COUPLING

DRG NO A5407-P-16 REV

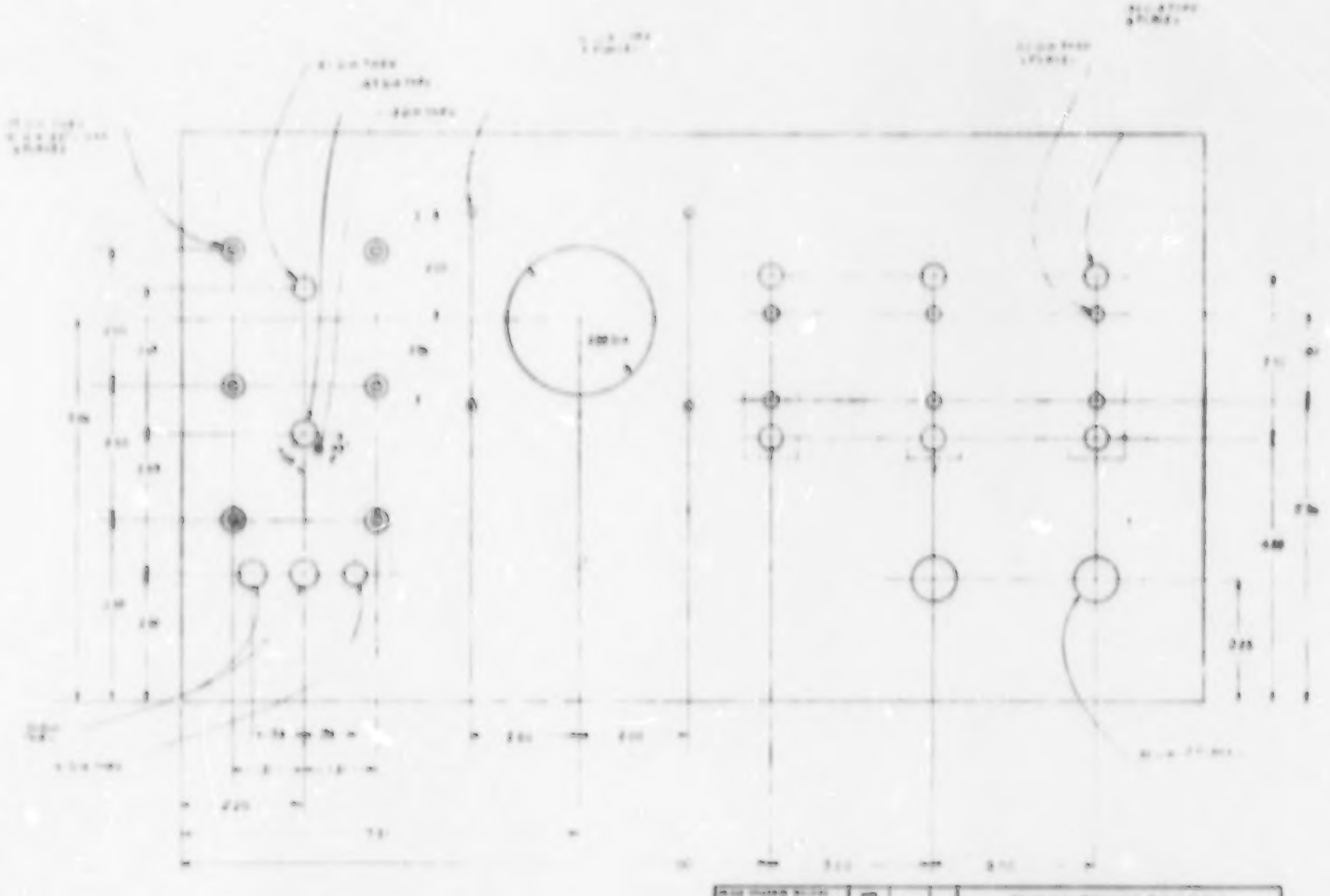
SCALE Full WT CALC ACT

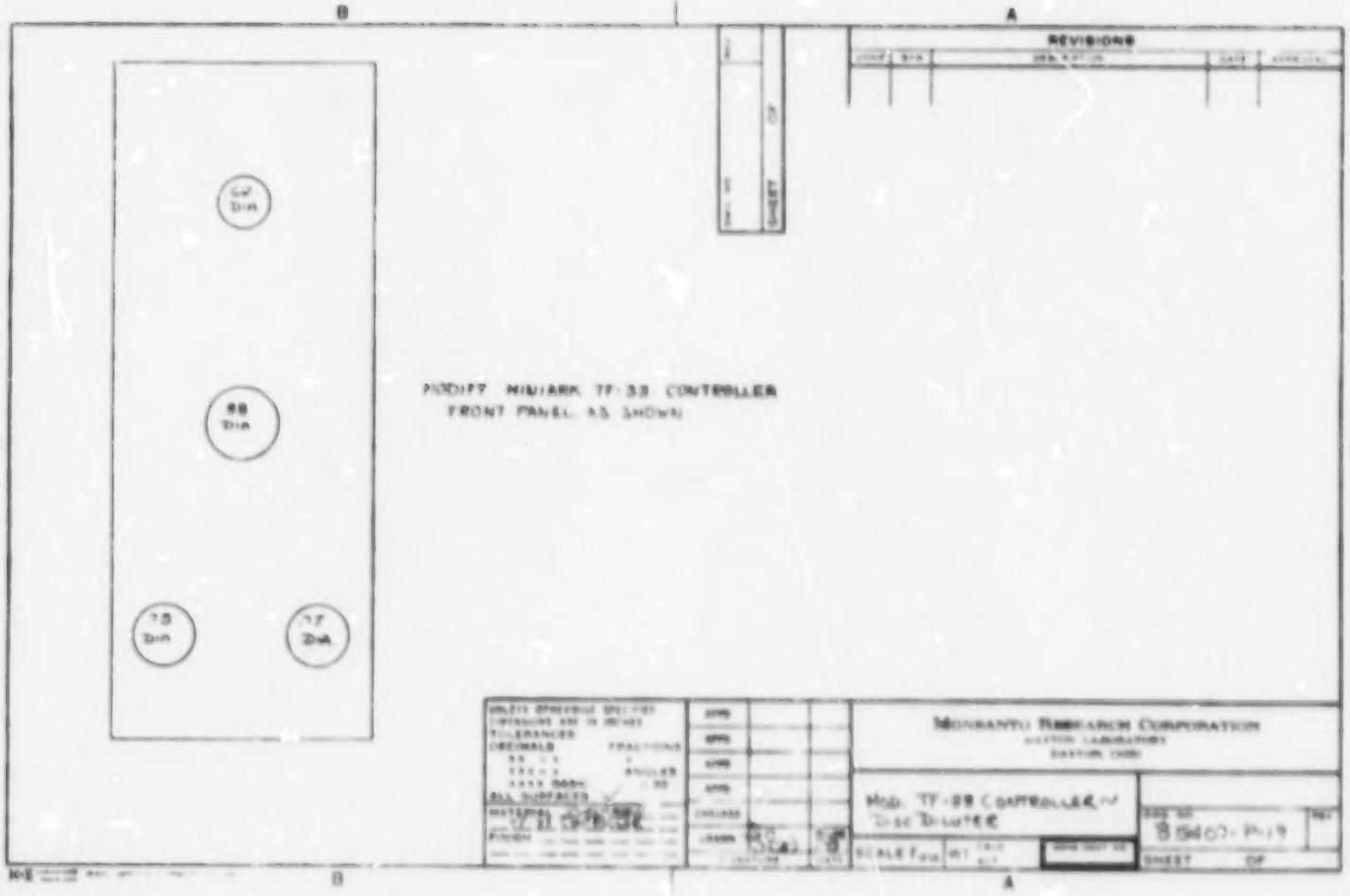
SHEET OF

M-2



67a




REVISIONS
SHEET
MODIFY MINIARK TF-33 CONTROLLER
FRONT PANEL AS SHOWN
.68 Dia
.88 Dia
.75 Dia
.77 Dia
MINIARK TF-33 CONTROLLER
DIE CASTING